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RESEARCH NEEDS FOR WATER QUALITY CRITERIA

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MEMBERSHIP OF THE U. S. DEPARTMENT OF THE INTERIOR'S NATIONAL TECHNICAL ADVISORY COMMITTEE TO THE FEDERAL WATER POLLUTION CONTROL ADMINISTRATION ON RESEARCH NEEDS FOR WATER QUALITY CRITERIA

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CONTENTS

Committee Membership ---------------------------------- i
Introduction -- 1
Section I: Recreation and Aesthetics ------------------ 3
    Introduction -------------------------------------- 4
    Aesthetics -- 4
    Recreation -- 5
        General considerations ------------------------ 5
        Detection of organisms ------------------------ 5
        Indicator organisms --------------------------- 6
        Pathogenic organisms -------------------------- 7
        Correlation of indicators and pathogens ------- 8
        Nonpathogenic factors in primary contact recreation ---- 8
        Secondary contact recreation ------------------ 9
        Research on control and treatment ------------- 9
        Effects of pollution on recreation ------------ 10
    Application of research results ------------------- 11
Section II: Public Water Supplies --------------------- 13
    Introduction -------------------------------------- 14
    Research Needs ------------------------------------ 14
Section III: Fish, Other Aquatic Life, and Wildlife --- 19
    Summary --- 20
    Introduction -------------------------------------- 26
    Research Approaches, Methods, and Procedures ------ 27
    Research Needed ----------------------------------- 31
        Chemical Investigations ----------------------- 31
        Environmental Requirements of Aquatic Organisms ---- 33
            Dissolved Materials ----------------------- 33
            Turbidity, Settleable and Suspended Solids ---- 33
            Color and Transparency -------------------- 35
            Salinity ---------------------------------- 35
            pH -- 35
            Temperature ------------------------------- 36
            Oxygen ------------------------------------ 37

        Carbon Dioxide ---------------------- 38
        Nutrients and Nuisance Growths --------- 38
      Toxic and Damaging Materials------------- 39
        General ------------------------------ 39
        Oils---------------------------------- 40
        Highly Toxic Wastes------------------- 41
        Radioactive Wastes-------------------- 44
      Ecological Field Investigations ------------ 44
        Methods------------------------------- 44
        Environmental Requirements ------------ 45
          Temperature------------------------ 45
          Dissolved Oxygen------------------- 45
        Toxic Materials----------------------- 46
      Wildlife ---------------------------------- 47
Section IV: Agricultural Water Supplies ------------------ 49
    Introduction------------------------------------ 50
    General -- 51
    Water Quality for Agricultural Uses ------------ 53
      Farmstead Water Supplies ----------------- 53
      Water for Livestock ---------------------- 55
      Water for Irrigation --------------------- 58
    Water Quality Problems Related to Agricultural Practices-------------------- 68
        Salinity ------------------------------- 68
        Nutrients------------------------------- 69
        Sediment ------------------------------- 70
        Organic Wastes ------------------------- 71
        Pesticides------------------------------ 72
Section V: Industrial Water Supplies -------------------- 75
    Introduction------------------------------------ 76
    Pollutant Effects ------------------------------ 77
        Effect of Effluents on Coliform and Fecal Coliform Bacteria and Pathogens ------- 77
        Effects of Colored Waters on Sports Fishing ---------------------------- 79
        Significance of Thermal discharges ------ 79
        Effects of Biological Refractory Organics---------------------------- 79
        Stormwater Overflow -------------------- 80
        Accidental and Uncontrolled Spills ------- 81
        Early Warning System -------------------- 81

Effects of Storage on Water Quality ---------81
Effects of Agriculture Pollution (Nutrients, Pesticides, Salinity)-----------82
Ground Water Pollution --------------------82
Interaction of Waste Effluents --------------83
Flow Measurement, Sampling, and Analysis-----83
Pollution Surveillance Equipment -----------83
Sampling Program, Economics, and Validity----------------------------------84
Improved Analytical Procedures ------------84
Viruses: Detection and Quantification--------85
Biochemical Oxygen Demand: Determination, Evaluation, and Revision --------85
Control, Treatment, and Disposal--------------85
Control ------------------------------------86
Treatment----------------------------------87
Integration of Industrial and Sanitary Wastes----------------------87
Refractory Waste Treatment-------------87
Reduction of Phosphate Pollution ---------88
Reduction of Colloidal Materials ---------89
In-river Treatment ---------------------89
Disposal -----------------------------------89
Sludge Disposal -----------------------90
Liquid Refractory Wastes ---------------90
Intermittent and Seasonal Discharges -----90
Small Rate Discharges ------------------91
Social, Political, and Economical Considerations --------------------------------92
Development of Optimum Techniques for Water Management-----------------92
Utilization of Water of Impaired Quality for Industrial Processing -------93
Impact of Wastewater Effluent Requirements on Water Use -------------------93
Economics of Altering Water Quality -----93
Economics of River Basin Water Management -------------------------94
Air Pollution - Water Pollution Interchange--------------------------94

Logic of Sewer Rental Charges for Industrial Wastes ------------------94
Logic of Charges for Water ------------95

INTRODUCTION

The work of the National Technical Advisory Committee on Water Quality Criteria was authorized by the Water Quality Act of 1965, which established the legal machinery for adopting water quality standards for interstate (including coastal) waters. This Committee was appointed by the Secretary of the Interior for the primary purpose of recommending water quality criteria for the following major water uses: (1) Recreation and Aesthetics; (2) Public Water Supplies; (3) Fish, Other Aquatic Life, and Wildlife; (4) Agriculture; and (5) Industry.

An additional assignment of the Committee was to define research needs for these same five major water uses. This report is the fulfillment of the second task.

The Committee found in carrying out its charge that there was a need for much information and ~~that~~ the unknowns still outweigh the knowns in the area of water quality requirements. ~~The~~ Needs include such things as: ~~(1)~~ determining the limiting and desirable levels of dissolved oxygen and temperature necessary to protect aquatic life; ~~(2)~~ defining acceptable bacteriological limits in waters used for recreation; ~~(3)~~ defining limits on minerals and taste and odor causing materials in waters used for agriculture and public water supplies; and ~~(4)~~ determining the chronic effects which minute concentrations of countless pollutants might have upon life systems. All of these problems and others, such as sampling techniques and analytical procedures, are referred to in the ~~five~~ reports, on research needs.

The Committee membership comprised a wide range of outstanding expertise related to the various major water uses. The work of the Committee, including this report, was organized along those lines. Discussions within the Committee were frank and wide-ranging. Opinions were freely expressed and, as a result, Committee members in some cases dealt with problems not directly within their respective fields of specialization but which have an impact on the water uses they were concerned with. This situation is reflected in the overlapping discussions in some sections of this report.

The Committee's work has contributed substantially to determining research needs for water quality criteria. It should be understood that Committee recommendations may not necessarily coincide with the research goals, priorities, or policies of various Department of the Interior agencies. However, the report should be a valuable reference for water pollution control administrators and researchers concerned with various pollution problems, whether these individuals represent regulatory agencies, private groups, or academic institutions.

RECREATION
AND
AESTHETICS

INTRODUCTION

It is not our intention in this brief resumé of research needs to propose detailed research programs, but rather to point out various aspects of the problem of relating water quality requirements to aesthetics and recreation and to indicate lines of endeavor that seem to be most promising.

The Committee recognizes that complete satisfaction of the research needs contained herein entails and extensive program requiring appreciable expenditure of funds, manpower, and time. However, it would recommend maximum effort consistent with available resources benefit from those we have obtained.

AESTHETICS

The Committee sees little to be gained on a national level from an extensive research program to refine aesthetic requirements to numerical values because these requirements will vary radically from community to community. Only in the case of key factors for limited waters within restricted areas do the potential returns seem to justify such efforts. For example, the unacceptability of algal blooms as encountered at Santee or the muddiness of many Midwestern rivers in the setting of Lake Tahoe seems to justify refining to meaningful numerical values the requirements for nutrients and turbidity in the latter waterbody.

On the other hand, there are aspects of aesthetics in which one would expect great returns from added research efforts. Research on improved control over discharge of materials producing aesthetically objectionable conditions offers the possibility of widespread gains of value not only to aesthetics but to other fields of water use as well. Similar gains may be realized from studies on the economic and sociological aspects of aesthetics as they relate to land values and human acceptance of water for various uses in specific localities.

RECREATION

General Considerations

In association with recreational use of waters, and more specifically, primary contact recreation, there are far more problems yet to be solved than ones that have been solved. In an attempt at an orderly approach, the Committee wishes to consider first the research needs associated with the health aspects; secondly, those associated with availability and economics; and finally, the integration of these facets.

While some of the research needs that will be discussed, such as development of procedures for detection of indicator organisms and pathogens, may have widespread application, it is our belief that the need to properly assay the impact of variables will necessitate local or regional orientation for much of the research. These variables include physical and chemical variations of water quality, the impact of foreign (in the sense of non-local) populations, and water borne diseases and their sources within given areas.

Detection of Organisms

Since organisms form the basis for the other phases of research into the health aspects of water-contact recreation, it seems appropriate to begin with a discussion of the research needs associated with tests or procedures for detection of organisms. These procedures are most readily categorized as those for detection of indicator organisms, viruses, and non-viral pathogenic organisms.

There are a number of factors that must be considered in such procedures with their relative importance dependent to a considerable extent on the intended application of the procedure. For example, if a procedure is to be used primarily for monitoring the suitability of waters for contact recreation, costs (in terms of manpower, time, materials, etc.) should be held to a minimum, technical training requirements for personnel should be reasonable, and the time lag in obtaining results should be kept at a minimum. If, on the other hand, the procedures are to be used largely in research, more complex and more costly refinements may be fully justified. Reliability and specificity in qualitative and quantitative detection of an organism or group of organisms are of prime importance in all cases. Similarly, the detection of organisms at very low levels of concentration may be desirable, particularly in the case of pathogens. This may be accomplished by appropriate sample concentration techniques as well as by development of extremely sensitive detection procedures.

Indicator Organisms

As stated in its report, "Water Quality Criteria for Recreation and Aesthetics," the Committee believes that monitoring for indicator organisms offers the best single solution to determining the sanitary suitability of waters for contact recreation. However, we are aware of the many failings of monitoring based on our present level of knowledge.

It was pointed out in the report that total coliform organisms are such non-specific indicators of contamination that may constitute a potential health hazard as to be of little value and the recommendation was made that present water quality standards be based on fecal coliform organisms. Monitoring based on this indicator should allow maximum use of water for recreation and restrict use only when there is a good probability of health hazards.

Fecal coliform organisms rather specifically indicate contamination originating from warm blooded animals. Inasmuch as many pathogenic forms are shared by man and other warm blooded animals, differentiation of the source of contamination by species is not vital to evaluation of the suitability of water for recreation. However, in epidemiological studies and for development of pollution control techniques, it will be desirable to determine the specific sources of the organisms.

Some clarification of source in fresh waters may be obtained by comparing concentration of fecal coliform organisms to that of fecal streptococci, with a ratio of 0. 6:1 or less indicating an origin other than domestic sewage. More definitive identification of sources is a possibility through use of specific organisms such as S. bovis, which is quite prevalent in fecal material from cows. Additional research on indicators of specific sources of contamination such as various classes of domestic livestock, poultry, rodents, and wildlife (both avian and mammalian) is needed for monitoring the effectiveness of pollution control activities. This aspect of monitoring may be supplemented, or to some extent replaced, by adequate sanitary surveys. However, sanitary surveys must be much broader in scope than mere determination of the presence or absence of sources of household, municipal, or industrial wastes.

In addition to the aforementioned research needs associated with monitoring, there is a great need for development of techniques that will indicate potential presence of pathogenic viruses. Perhaps in the case of untreated or non-disinfected wastes the normal indicator organisms (when supplemented by appropriate studies on rates of die-off) may serve adequately, but in the case of disinfected wastes this is not true. A logical solution would seem to be a tracer organism that could be added to the waste prior to treatment. Ideally, such an organism would have a susceptibility to treatment (particularly disinfection) and a rate of die-off similar to that of viruses and would be of very limited natural occurrence in both polluted and unpolluted waters.

There is a particular need to include estuarine and marine waters in the studies associated with indicator organism. At present, our body of knowledge related to sanitation in salt water is even more limited than that for fresh waters.

Pathogenic Organisms

In the opinion of the Committee, the greatest values to be realized from work on pathogenic organisms will be in applied research rather than in field application for monitoring. As mentioned in the National Technical Advisory Committee Report, the multiplicity and complexity of tests, time lapse, and numerous other factors impede the use of pathogenic organisms for monitoring. However, it is the presence of pathogenic and not indicator organisms that is of true significance in recreation waters; thus, the importance of pathogenic organisms and their effect on people in contact areas should not be minimized. But lacking a complete continuous monitoring technique for all pathogenic organisms, water quality based on the indicator system must be used to show the potential for the occurrence of pathogens in time and space.

One basic area that might profit from added research is identification of pathogenic organisms. Most of the present procedures, particularly those for pathogenic viruses, require complex and time-consuming steps involving isolation followed by culturing before identification can be made. Shortened and simplified procedures would be a boon to research on the health aspects of water-contact recreation and are an absolute necessity if pathogens are to be used for monitoring. Appropriate endeavors might include techniques for sample concentration followed by highly sensitive identification through use of antigen-antibody reactions or detection of specific nucleic acids or similar substances with gas chromatography or other types of instrumental analysis.

A second phase of research on pathogens which would be of value in assessing suitability of waters for contact recreation is a concerted effort to determine prevalence in various mammalian and avian populations of pathogenic organisms affecting man. This would include assessment of the impact of the recreationist himself on water quality. The Committee would envision these activities as not restricted to laboratory or clinical research, but broadened to include field investigations with a regional and local orientation. Moreover, all types of pathogens (viral, bacterial, protozoan and metazoan) should be included; not only those producing serious physiological disturbances, but also those of significance only as nuisance such as swimmers itch. Within its overall scope, this program could utilize information compiled by local, State and Federal agencies involved with public health, agriculture and wildlife management; public and private educational and research institutions; and physicians and veterinarians in private practice.

Two additional and somewhat related research areas are the degree to which various pathogens are waterborne, and the levels of exposure constituting infective doses. Infectuous hepatitis may be cited as an example of a disease whose relation to water-contact recreation might be clarified by such research. It seems that solutions for these questions are most readily obtained through carefully designed and conducted epidemiological studies. The Committee would suggest most emphatically that design of epidemiological studies include analysis of the effects of the full range of physical, chemical and biological variations of water quality in marine, estuarine and fresh waters.

Correlation of Indicators and Pathogens

If maximum values relative to monitoring and epidemiological studies are to be realized from research on indicator and pathogenic organisms, there must be extensive work on correlation of the expected prevalence of the two groups in recreation waters. A logical approach would seem to be controlled time-lapse studies of die-off and regrowth rates of both indicators and pathogens over a wide range of chemical, physical and biological variations in water quality. The results of laboratory or pilot studies should be confirmed by selected field studies in marine, brackish and fresh water environments under different degrees of enrichment.

Nonpathogenic Factors in Primary Contact Recreation

Two additional factors we believe merit some research efforts are temperature and injuries as they relate to recreation users. Both of these factors, and especially injuries, are as much or more a matter of concern for the recreation planner as for persons associated with general water quality programs.

The available data on the effects of temperature with prolonged immersion is based on low levels of activity. There is a need to supplement this data with information on the physiological effects of temperature related to various degrees of activity. In the case of injuries, there is a need for epidemiological evaluation on the effects of various physical factors of water quality such as turbidity and color.

Secondary Contact Recreation

It will be noted that the preceding discussion of the health aspects of recreation has been devoted to primary contact recreation to the exclusion of secondary contact recreation. Information needed for managing water quality for secondary contact recreation (boating and fishing) as related to its impact on the health of the recreation user is virtually nonexistent. The Committee strongly recommends a research program to amass the epidemiological experience or records that would permit establishment of meaningful bacteriological criteria for so-called secondary or casual contact with water. As an alternative, information needed for managing water quality for secondary contact recreation may be secured by research on the relative degrees of exposure and risk of infection represented by primary and secondary contact recreation. Either approach would lead to an improvement over criteria by "guestimate" based on use of arbitrary application factors and limited epidemiological data for primary contact recreation.

A second aspect of research in the field of secondary contact recreation is that related to the recreation resource, particularly the water-associated fauna. Since research needs associated with environmental requirements of the fauna are the primary responsibility of the Committee for Fish, other Aquatic Life and Wildlife, we will not dwell on this subject in depth. However, we would suggest a detailed evaluation of the recreation potential to be realized from waters of less than optimum quality for production of aquatic life. With increasing demands for recreation and increasing pressures on our supply of water, an appreciable portion of our future recreation may be derived from such waters.

Research on Control and Treatment

There are urgent needs for research on treatment and control of wastes affecting recreation uses of receiving waters. Control of wastes limiting recreation use is especially needed in and near population centers where needs are greatest and problems most difficult.

To date, most investigations on the effectiveness of various types of treatment have dealt with reduction of BOD and solids. With a few exceptions of limited scope, even those concerned with reduction of bacterial concentrations in the effluent have been based on organisms that are indicators rather than pathogens. New studies based on pathogenic organisms should permit pathogen reduction (an important aspect of water quality enhancement) to take its proper place in design, modification and operation of treatment, and thus add to the recreation usefulness of our water resources.

There is also a need for research to develop improved methods for disinfection of domestic sewage, other wastes, and stormwater runoff. Chlorination as generally practiced has been shown to be ineffective in controlling many of the pathogens, with variability in degree of control greatly influenced by removal of pollutants in other treatment steps. This deficiency should be remedied by research on the level of chlorination necessary for effective disinfection of wastes of different quality. In addition, we would suggest thorough investigation of the effectiveness, safety, and economics of waste disinfection utilizing other chemicals, radiation (ultraviolet, sonic, ionizing, etc.), pH adjustment, electrical charges and other methods or combinations of methods. Such investigations may lead to effective disinfection that is less dependent on effluent quality.

A third related phase of research, and one more directly associated with contact recreation use of waters is investigation of effective control or disinfection to maintain desirable sanitary levels at bathing beaches. These endeavors would be particularly applicable to public beaches of marginal quality in major population centers. Disinfection studies could be as specific as alteration of basin hydrology tailored to the individual case. Similar studies might be applied to problems associated with aesthetic conditions in such areas.

Effects of Pollution on Recreation

A national assessment of the effects of water pollution on recreation use and value of water resources would be helpful in formulating broad guidelines for recreation. Local and regional variations in water quality conditions, recreation demands and habits, and economics of control suggest that policies for quality management might be best developed on a case-by-case basis.

Research on effects of pollution on recreation use involves two major study areas -- those related to health and those related to aesthetics or human acceptance.

It is timely now to formulate research efforts to gauge the impact of the water quality standards program on recreation use. Among the questions arising are: 1) What restrictions are placed on recreation use by setting of various bacterial levels in the criteria? 2) Are these criteria restricting existing use? 3) Does the use of fecal coliform organism as an indicator make it possible for public health officials to approve of contact recreation in waters previously considered unsafe on the basis of total coliform counts?

An additional research need related to availability and use of recreation waters is investigation of the influence of aesthetic factors on human attitudes toward acceptance of water conditions. These studies should consider both aesthetic conditions perceptible to the senses and aesthetic conditions of psychological importance, such as known or suspected bacterial contamination. Results of the studies, along with measurement of increased recreation use concurrent with improved water quality, could play an important role in determining the orientation of a continuing water pollution control program.

Refinement of economic data is needed. To date, most economic studies have been related to input for secondary contact recreation (fishing and boating) to the exclusion of output. For primary contact recreation the lack exists for both input and output. The compilation of economic data on the output for recreation is rendered more difficult by the necessity of assigning dollars and cents values to intangible benefits such as human enjoyment and satisfaction.

The Committee recommends strong benchmark research in terms of inputs and outputs of recreation as they relate to local and regional economic benefits and to intangible benefits. Such studies are essential to placing recreation in its proper perspective in development of water management programs.

Application of Research Results

The Committee believes that research needs associated with health must be met if criteria and classification for primary contact recreation water are to attain proper balance between safeguards for the public health and restriction on availability of water for recreation use. Satisfaction of these research needs would permit further refinements in setting criteria and classifications, possibly to the extent of slightly reduced safety factors for health assurance if demand for and availability of recreation waters, economics of water quality enhancement and recreation values, and public acceptance justify such actions. Similarly, they might indicate the need to remove some waters from recreation use or serve as justification for more stringent treatment requirements.

A final recommendation, not associated directly with research, is that there be an intensified public information and education program to fully apprise the public of all aspects of water management programs, including the responsibilities of the individual in maintaining a desirable aquatic environment. Public opinion should be molded by knowledge, not subterfuge or emotionalism.

PUBLIC WATER SUPPLY

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INTRODUCTION

Research needs in the field of public water supply range from age-old problems, which modern technology has failed to resolve, to brand new problems which modern technology continuously creates. The outstanding examples are tastes and odors. Tastes and odors have always been a problem to water works operators. The increasing array of exotic organics being unloaded upon the nation's waterways promises to make the problem ever worse. For this reason the Committee commences this list of research needs with the redundant request for more effort, more funds, more imagination, more help with this difficult problem.

The public is generally quite complacent about its water supply--until something brings it to their attention. Examples are water shortage, sudden unsavory odor, or an augmentation of fluorides to optimum levels. Then the public becomes very much concerned--even emotionally concerned. But the day-to-day struggle with poor quality waters by water treatment plant operators goes largely unnoticed.

As population increases and technology becomes more complex, problems can be expected to mount. The public with more leisure time will insist upon more opportunity for water-oriented recreation. Industry and agriculture will require more water for increased production. Faced with a constant supply, these pressures will result in greater use and reuse, and hence, diminishing quality.

In spite of this bleak picture, however, there are hints that research on the physiological effects of water pollutants, both man-made and natural, may pay off handsome dividends in the field of public health. Such research is difficult, lengthy, and costly. Nevertheless, it is time for more of man's energy, wealth, and ingenuity to be diverted to this area of endeavor. The rewards are well worth the effort.

Specific expressions of interest of the Committee follow.

RESEARCH NEEDS

The problem of tastes and odors in public water supplies remains the most vexing problem of water treatment plant operation. Sources of tastes and odors are numerous and analytical techniques for many of the causative agents are either cumbersome or may not even exist. The threshold taste and odor procedure, in spite of its inadequacies, remains the only tool available to evaluate these problems. Ways of judging tastes and odors by chemical or other specific analytical techniques are needed. Other related requirements include:

1. Information on the effects that minerals in water have on taste, odor, and public acceptance;

2. Threshold odor values of various dissolved organic chemicals, singly or in combinations and algal relationships;

3. The influence of reservoirs, as well as their management, on tastes and odors;

4. Techniques for the control of runoff from farms and forests and the relationship of runoff to tastes and odors.

Another area of much concern to the Committee is the lack of suitable analytical techniques for the measurement and control of dissolved organic materials. Rapid, specific, and reliable techniques are needed that will enable the monitoring and control of these materials for the protection of public water supplies. Associated problems include:

1. Improvement of sampling techniques to provide more truly representative samples;

2. More study, development, and application of CCE and CAE techniques;

3. Standardization of biodegradability tests with which to screen discharges;

4. Determination of persistence of various organics and their products of decomposition;

5. The development of a good indicator of organics as related to water treatment plant problems of operation;

6. More information on the distribution (by types and concentrations) of pesticides in various waters used for public water supply.

Methodology for the enumeration and isolation of bacteria and viruses requires additional research and development. More specifically, microbiological problems include:

1. Enumeration of viruses in dilute suspensions;

2. Salmonella relationships in polluted waters; sources, quantitating techniques, survival in waters and on watersheds, and regrowth;

3. Validity of coliform and fecal coliform criteria in the light of regrowth in receiving waters;

4. The effect upon pathogens of chlorinating sewage treatment plant effluents;

5. Continuing study of exotic pathogens (those from foreign sources) and their introduction into the watersheds and hence waterways of the United States.

The Committee is concerned with the lack of knowledge on eutrophication and enrichment phenomena. Specific questions are:

1. What would be the effect on nuisance algal populations of minimized nitrate concentrations?

2. What nitrate sources are of significant importance to public water supplies?

3. Can waste waters be denitrified within the economic framework of our present society?

4. How much will better sludge management at water and waste treatment plants improve receiving water quality?

5. What methods are currently feasible to minimize phosphorus concentrations in waste water effluents? To what extent must these methods be employed now?

6. What is the magnitude of seriousness of the eutrophication problem on domestic water supplies?

Waste treatment operational questions are introduced in two other ways.

1. Reliability of performance;

2. Return to an operational practice of oxidizing ammonia.

Physiological effects of the many constituents found in waters are of great concern to the Committee. Questions posed include:

1. Is the present limit on nitrates and nitrites far too conservative?

2. Are there other constituents in water involved in methemoglobinemia?

3. What are the chronic physiological effects of boron in water?

4. What is the physiological significance of minerals or its constituents, pesticides, herbicides, and other organics, individually or in combination?

Lastly, the Committee expressed a desire for additional studies of the economic effects of water quality and of the effects of storm waters and combined storm water overflows on receiving water quality.

FISH OTHER AQUATIC LIFE, and WILDLIFE

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SUMMARY

The objective of this proposed research is to determine the water quality requirements of aquatic life and wildlife. To accomplish this objective there must be an effective, efficient, adequately supported, and continuing national research program. This program must be planned and carried out so that adequate data are secured to establish: (1) maximum or minimum environmental conditions and concentration of toxicants which shall not be exceeded; (2) environmental conditions and concentration of toxicants which can be tolerated for short periods without significant harm; (3) the range of environmental conditions and concentrations of dissolved materials which are not harmful and those which are favorable and required for all important species.

Research Approaches, Methods and Procedures

Research must be conducted to determine new or better methods for the following purposes.

1. To devise or modify and develop equipment and methods for the collection, isolation, and production of all life stages of important aquatic organisms so they are available at all times in sufficient numbers for bioassay studies.
2. To devise or modify and develop effective bioassay methods and other procedures for determining environmental conditions and concentrations of potential toxicants which should not be exceeded, which can be tolerated for short periods and which are favorable and essential for

the survival, growth, reproduction, and general well being of all important groups of aquatic life and wildlife.

3. To develop facilities, equipment and ecological, analytical, physiological, toxicological, and other methods for the field and laboratory determination of the effects on the biota of alterations in environmental conditions and the presence of various concentrations of potential toxicants.

4. To develop special equipment or methods for determining or developing:
    a. The effects of the environment on the total biota and individual organisms to provide a synthesis with predictive values for indicating the responses of a species or biota to a given change in the environment.
    b. The active and standard metabolic rates under multifactorial combinations of various environmental components in the presence of pollutants.
    c. New and more specific methods for detecting sublethal effects of toxicants such as the oxygen-nitrogen ratio and bioenergetics.
    d. Methods for sampling and monitoring, instrumentation for automatic continuous sampling, more precise field methods for determining effects of pollution, and determination of standing crops, productivity, and population dynamics.
    e. Autopsy techniques.

Chemical Investigations

Research is needed for:

1. The development of microanalytical and other toxicological methods for the detection and quantitation of toxic materials in water and tissues at the extremely low concentrations at which they are either toxic or safe under conditions of continuous exposure.

2. The development of analytical methods of the

specificity, sensitivity, and accuracy essential for toxicological studies.

3. Developing methods for using radioactive tracers to aid in determining metabolic pathways of toxicants, their breakdown products, and their turnover time or concentration in tissues.

Environmental Requirements of Aquatic Organisms

Research should be carried out to determine the environmental requirements of all stages of the life history of important sensitive species to indicate lethal levels or sublethal but harmful levels of environmental factors, and the ranges of these factors that are favorable and promote the production of a desirable crop. Research for these purposes will include the following studies.

Temperature and dissolved oxygen: Laboratory and field research should be carried out to determine the following:

1. What is the significance of daily and seasonal fluctuations in temperature and dissolved oxygen?
2. How rapid may changes be without exerting an adverse effect?
3. Does it matter if the fluctuations are out of phase with the natural cycle?
4. What are the effects of wide fluctuations above or below the daily mean and how much can temperatures be raised and dissolved oxygen concentrations lowered from natural conditions without harming the biota or causing a change in its makeup?
5. At what termperatures and dissolved oxygen levels will desired species be replaced by undesirable competitors?
6. What are the trade-offs relative to increased growth and total productivity versus parasites, disease, and mortality of different life stages?
7. What levels of temperature and oxygen are harmful, tolerable, and favorable for all the important species at all life stages, including egg, nymph, larvae, fry, etc.?
8. What are the effects of changes in daily and seasonal temperatures on migration, scope of

activity, and the toxicity of waste materials?
9. What are the maximum temperature and minimum oxygen levels that can be tolerated for short periods without harm?
10. What are the allowable overall increases in temperature at different seasons that do not produce undesirable effects on the biota?
11. What are the allowable and favorable levels of temperature and oxygen for all important species?
12. What are the requirements for low temperatures in the life cycle of important organisms?
13. What are the effects of stress due to pollutants on the temperatures which are lethal, tolerable, or favorable?
14. What are the beneficial effects of the addition of heat?

Nutrients and eutrophication:

1. What are the nutrient requirements of desired species and the organisms in their food web?
2. How much can nutrient conditions be changed from the normal without detrimental effects?
3. What are the amounts of nutrient or fertilizing materials which may be desirable from the standpoint of productivity?
4. How do changes in nutrient balance, due to additions of wastes or other materials, affect the abundance of different groups or species of organisms and the eutrophication of a water?

Other Environmental Factors

Dissolved materials: Determination of high or low concentrations which can be tolerated for short periods and the favorable range of concentrations or levels for the following: dissolved solids, suspended solids, settleable solids, turbidity, color, salinity, pH, and carbon dioxide.

Toxic Wastes and Materials

The following research should be conducted in connection with the toxicological program.

1. Long-term studies with the most sensitive species

and life stages of important organisms should be conducted. They would serve to determine the maximum concentration of potential toxicants which, under the extremes of allowable environmental conditions, are not harmful with long-term or continuous exposure as indicated by survival, growth, activity, reproduction, and the general well-being.

Studies for determining long-term effects should include the following:

a. Behavioral studies to detect any changes that may render the organism less capable to cope with the natural environment or make it more susceptible to predation or disease.

b. Physiological studies to detect any adverse functional effects of exposure to sublethal concentrations of toxicants.

c. Investigations of effects on enzymes or endocrine gland functions.

d. Metabolic studies to evaluate changes due to the action of toxic materials.

e. Histological, histochemical, and pathological studies.

2. Devise, develop, and test short-term methods for determining long-term effects of toxic materials on aquatic organisms through the use of metabolic, physiological, biochemical, behavioral, histological, histochemical, histopathological, enzymatic, hormonal, stress, energy transfer and balance, and other tests carried on in conjunction with the long-term laboratory tests.

3. Studies to determine the following:

a. The effects of non-lethal damage during any developmental stage on sucessive stages.

b. The effects on all life stages of sublethal exposure during the most sensitive stage.

c. Comparative studies of the effects of exposure during the most sensitive stages and the complete life cycle exposures.

d. The mode of action of toxicants and mechanisms of detoxification.

e. The interaction of two or more toxicants, synergistic and antagonistic effects, and different modes of action.

4. Determination of application factors for use with TL_{50} values to determine safe discharge rates for industrial wastes.

Radioactive waste: Studies should be conducted to determine allowable levels of radioactivity in the environment which are harmful to the aquatic biota or produce concentrations in the bodies of aquatic organisms which render them unsuitable for food.

Tastes and odors: Research to determine: (1) materials and organisms responsible for taste and odors in water supplies and the flesh of edible organisms; (2) the maximum concentrations of these materials which do not produce objectionable tastes or odors and methods for their control.

Wildlife Requirements

Research to determine new or better analytical methods for identification and quantitation of nutrients, toxicants, and trace elements. Also, we need to know about their movement through the food chain, their biological magnification, and where, when, and in what form they accumulate. Other needed investigations include: (1) Studies on the sources, disposal, treatment and elimination of oils from the habitats of waterfowl. (2) Studies on the effects of pollutants or changes in water quality on waterfowl and wildlife food organisms. (3) Determination of concentration of herbicides (used for controlling nuisance plants) which do not produce long-term pathological effects or tainting. (4) Determination of the effects of chemical mosquito control on waterfowl and other organisms in the biota.

INTRODUCTION

Research aimed at improving and maintaining the environment of aquatic organisms is not limited in objective to the benefit of these organisms. It is meant to provide adequate supplies of aquatic life and wildlife for man's use. Thus, in approaching this problem, the question should be, "What is the quality and quantity of aquatic resources that man now has and should have in the future, and how can these resources be restored, protected, maintained, and enhanced?"

To meet these problems, the determination of water quality requirements for aquatic life is of outstanding importance. If a fresh water is suitable and safe for aquatic organisms, it can be rendered safe for human consumption by water treatment methods now in existence. If fresh water is satisfactory for aquatic plants and aquatic organisms, it will in most cases be satisfactory for livestock, wildlife, and irrigating crops. If a water is satisfactory for aquatic life, it will in general be aesthetically pleasing and suitable for most recreational uses. Water suitable for aquatic life should be entirely suitable for industry, navigation, and power. The establishment of water quality requirements for the protection of aquatic life resources is the key to the protection of most uses made of water.

In the past, only a small percentage of the available funds for controlling water pollution was utilized for the determination of water quality requirements for aquatic life and wildlife. Biological investigations were not carried out in proportion to their importance. Very little attention was given to determining environmental requirements of aquatic organisms and the concentrations of potential toxicants that are not harmful in the aquatic environment. As a result, the volume of work was entirely inadequate to meet the problem. Because of deficiencies in equipment and personnel, studies were short term and dealt largely with acute toxicity. Little research was done on determining the long-term effects of pollution, or levels of potential toxicants that are not harmful in the aquatic environment.

It was obvious to the Committee from the onset of their task that present knowledge is inadequate for establishing definitive and conclusive water quality requirements for aquatic life and wildlife. This deficiency became more obvious as the preparation of the Subcommittee Report on Water Quality Criteria progressed and the present consensus is that the elucidation of water quality requirements has barely begun. Only research that is broad in scope, pertinently oriented, carefully designed, and adequately financed will supply the information essential for the protection of fish, other aquatic life, and wildlife.

RESEARCH APPROACHES, METHODS, & PROCEDURES

Short and long-term bioassays are presently the only tools available for determining the toxicity of particular pollutants to aquatic life; other approaches are needed to provide an understanding of the mechanisms involved. The basic need is methods to study the effects of the environment on the organism. These analytical methods should provide a synthesis with predictive value for assessing the response of a given species to a new situation. The theoretical basis for such an approach is not yet worked out. A beginning can be made, however, by describing the relationships between environmental factors such as temperature, slainity, and the concentration of respiratory gases and the ability of an organism to succeed. Measuring the performance of the active and standard metabolic rates in key organisms with multifactorial combinations of various components in the environment would provide a valuable base line for determining the effects of pollutants. Research units should be organized to study the environmental physiology of aquatic organisms. Goals of the units would be to determine metabolic requirements of activity under a given set of environmental conditions and to understand the mechanisms which make such performance possible.

Parallel studies should also be made on the effects of environmental changes on the structure of the aquatic community (kinds, distribution, and abundance of species), food pathways, and energy flow. It is essential that we learn how environmental changes affect ecosystems, how ecosystems react to toxicants, under what conditions a new desirable ecosystem may develop, and what types of stresses initiate a chain of reactions which are extremely difficult, if not impossible, to stop.

Selection of test organisms: The environmental criteria essential to aquatic life resources are difficult to determine. Extended, intensified, and sophisticated research is required to understand and manage the physical, chemical, and biological environment of fish, other aquatic life, and wildlife. The identification of environments which are (1) acutely harmful, (2) deleterious under chronic exposure conditions, or (3) safe under conditions of continuous exposure are very involved problems requiring research into the indefinite future.

These problems are compounded by (1) the large number of species involved, (2) the wide range of climatic conditions encountered in the United States and its territories, (3) the inherent differences among marine, estuarine, and freshwater environments, and (4) rapid industrial progress with the evolution of new contaminants, both real and potential.

These problems are so numerous that "short-cut" methods for finding answers must be developed. A desirable "short-cut" is limiting the total number of species of organisms to be studied, without creating serious gaps in the knowledge required. This should be possible because, in a given faunistic region, the number of abundant species which are important are relatively few in comparison to the total number in the area. It is recommended that test organisms be selected from those species of major economic and ecologic importance which can be held and reared successfully in the laboratory.

Even with this reduction, the number of species to be studied would be great and perhaps beyond the resources available for long-term studies. To help alleviate this problem, it is suggested that short-term sensitivity studies be done to determine which species and life stages are most sensitive to each environmental parameter or potential toxicant. Subsequent long-term studies to determine safe levels could be limited to the most sensitive species and life stages. The Committee believes that if the most sensitive species and life stages are protected, the entire biota will in most instances be protected. In some cases, it may be desirable to associate these studies on a priority basis with known wastes such as sulfite waste liquor or pesticides.

All the different faunistic areas of the Nation must be studied. These include Alaska, Hawaii, the Commonwealth of Puerto Rico, the Virgin Islands, Guam, and American Samoa, as well as the various river basins, and the principal coastal zones.

Studies should be made to determine: (1) the most important species in a particular biota; (2) methods for maintaining these species and their various stages in the laboratory so that they may be available in numbers sufficient for bioassays; and (3) the relative sensitivity of the various test organisms and life stages to the environmental factors and toxicant under investigation. By limiting sensitivity studies to those species peculiar to a given faunistic area, the total number under study could be limited, but collectively all of the nationally important species would be represented. When such an arrangement is operative, the species and life stages that are the most sensitive to each of the materials or wastes under study can be determined in a routine manner.

Methodology: Even with the simplified outline described above, the task of determining safe levels remains prohibitive from the standpoint of time and cost unless short-term evaluations can be correlated with specific long-term changes or effects. It is, therefore, essential to devise and test several biological parameters which may furnish rapid indexes of environmental requirements and safe concentrations of toxicants.

In developing short-term methods, it is recommended that the procedures used in human toxicology be evaluated for applicability. Tests should include behavioral, physiological, biochemical, enzymatic, endocrine, metabolic, histological, histochemical, histopathological, and various blood studies when they appear necessary.

Current methods of bioassay indicate the upper levels at which a potential toxicant is intolerable. Short-term bioassays as now developed and used, do not indicate whether an environmental factor is at an optimum level or if it is deficient. It is recognized that short-term bioassays are inadequate for many purposes and that flow-through and long-term bioassays are needed. Many substances which act as environmental poisons depress energy utilization. Studies of energy utilization should permit determining when substances are relatively innocuous as well as when and to what degree they slow metabolism. It is proposed, therefore, that new approaches to water quality be sought. By using the energy concept, it may be possible to express water quality criteria in a more adequate fashion and research to accomplish this goal should have priority. Some of the suggested short-term methods for determining long-term effects may be effective in reaching these goals.

Another gross type of index may relate oxygen utilization and nitrogen excretion (the 0_2:N_2 ratio) to biochemical imbalances and metabolic involvements. The oxygen-nitrogen ratio may possibly indicate the substrate being used for energy although it may not distinguish between fat and carbohydrates. Combined with CO_2 measurements, the ratios may offer a reasonable insight into the probable nature of substrates utilized. Abnormal oxygen-nitrogen ratios might result from certain types of sublethal metabolic anomalies that are caused by exposure to some toxicants.

Due to the magnitude of research needs for establishing meaningful water quality requirements for fish and other aquatic life, major emphasis will have to be placed on laboratory bioassays and on developing new and better bioassay techniques to meet existing problems. Increased efforts, therefore, must be expended to make bioassays more realistically reflect situations that occur in the field under natural conditions. Properly conducted experiments for comparing laboratory results with field observations will provide a sound scientific basis for establishing correct criteria with respect to temperature, oxygen, and other environmental requirements.

Methods must be developed for detecting subtle changes which indicate slow deterioration in the aquatic environment. These studies are essential if methods are to be developed for field use, because slow deterioration is the most difficult effect to detect and prevent. Subtle environmental conditions or low concentrations of potential toxicants must be studied. While these do not cause death or any easily-observed harmful effects, they will diminish growth and productivity, decrease the general well-being, or even in time destroy the population or eliminate a species. This is a problem similar to the one faced in the protection of man from the effects of air and water pollution. Death is obvious, but the gradual lowering of the general health, well-being, productive capacity, and slow deterioration of physical ability are not so obvious. There must be research to develop methods to detect, measure, evaluate, and control the subtle effects of pollution so that aquatic life resources on which we depend for food, recreation, and environmental pleasures can be restored and maintained.

RESEARCH NEEDED

CHEMICAL INVESTIGATIONS

In the past, chemical analyses made in connection with water pollution surveys and investigations have not been specifically directed toward toxicological problems. Analyses were confined to those materials for which analytical methods had already been developed. Usually, these tests were not sensitive or accurate enough to detect and quantitate materials at the low concentrations at which they are chronically toxic or safe. Also, tests were not designed to quantitate materials in their toxic forms. For example, total cyanide is measured as CN ion. This is not only misleading but inappropriate in a toxicological sense. Not all cyanides are equally toxic and when they are altered to and measured as CN ions, the result is that more cynaide is reported than actually occurs in one or several toxic forms. Experimental evidence indicates that it is the undissociated HCN molecule which is taken up by the organism. Thus, methods must be developed to detect and measure undissociated HCN in mixtures of complex cyanides.

This is essential for the meaningful toxicological evaluation of cyanide wastes. The same is true for the H_2S molecule, the un-ionized NH_3 and the NH_4OH molecule. Research on analytical methods for the development of micro-analytical toxicological procedures are essential for a sound water quality program. Specific analytical methods must be developed for all potential toxicants so that they can be measured in water and tissues at the very low concentrations at which they are chronically toxic. At present, only a few analytical procedures are available while several others have not yet been refined to meet the speed and sensitivity needed in toxicological work.

Research is needed in the field of biochemistry for the detection and quantitation of enzymes, metabolic products, hormones and changes resulting from exposure to toxic Materials. Special emphasis must be placed on developing analytical methods of the specificity, sensitivity, and accuracy essential in toxicological evaluations.

Chemicals or wastes that affect the different functions or organs should be evaluated; i.e., materials or families of products which affect respiration, digestion, reproduction and, on the molecular basis, the enzymatic systems involved in these functions. The particular physico-chemical changes tested should be those induced by materials introduced in the environment and known to produce definite stresses on the organism. These materials should be studied under both laboratory and field conditions. Furthermore, methods are needed to determine the effect of two or more biologically active materials that act either in unison, antagonistically, or synergistically. The causes and mechanisms of synergism and antagonism should be examined. Knowledge of the basic governing principles may serve in forecasting consequences that result from introducing specific products or wastes.

Methods should be developed employing radioactive tracers to aid in determining: toxicant-altered metabolic pathways, the metabolism of toxicants themselves, and their turnover time or concentration sites. Chemical and automated physico-chemical techniques should be adapted to complement ecological investigations.

ENVIRONMENTAL REQUIREMENTS OF AQUATIC ORGANISMS

Information is needed on the essential and optimal environmental requirements of aquatic organisms. While some work has been done on temperature effects and oxygen requirements, it has been limited to a few species that are adaptable to laboratory conditions. Precisely controlled and monitored research must be carried out with the important and most sensitive species of each of the major classes of organisms to determine favorable and allowable variations of environmental factors.

Some work has been done on short-term, acute lethal changes but the effects of long-term exposures must be evaluated. Data on the adaptive processes associated with the sublethal changes are essential in determining environmental conditions favorable for the well-being and the production of a crop of aquatic organisms. Studies are needed on the interactions of these environmental factors and the levels at which various combinations of these factors are most favorable. Research needed on some environmental factors will be listed and discussed in turn.

Dissolved Materials

Included under this heading are those materials which are not usually considered as potential toxicants because they are only toxic when present in abnormally high concentrations. The most common materials falling within this category are the salts of the earth metals. Studies should be made to determine for aquatic life the most favorable levels of these materials alone and in association with other materials, as well as the most favorable relative concentrations.

Turbidity, Setteable and Suspended Solids

Setteable and suspended solids and turbidity are of great importance in the aquatic environment. Any particle suspended in water absorbs light and decreases transparency. The effect of attenuating light cannot, however, be separated from physical, chemical, and biological effects of suspended materials on the aquatic biota. Only the decrease in the rate of photosynthesis can readily be linked to increased trubidity. However, sedentary organisms, their eggs, and larvae may be affected by the settling out of excessive amounts of silt, clay, detritus, and other materials suspended in the water. Plankton, especially the diatoms, may be covered with sediment and lose their buoyancy, thus settleable materials may effectively reduce the plankton population by settling out. The gills of fishes and bivalves can be injured by sediments, therefore, the maximum concentrations which are not harmful to important species should be determined.

Research is needed on the following:

1. The acute and chronic effects of various concentrations of presumably inert substances, such as calcareous silt, sand, kaolin and others can adversly affect the respiration, feeding, reproduction, growth and behavior of important aquatic species. Examples of these species are: bivalves, crabs, shrimp, lobsters, fishes of commercial and recreational importance, and their food organisms.
2. Behavioral effects of silting and sedimentation on the aquatic biota under simulated natural conditions where variables are controlled.
3. Physiological, chemical, and biological effects of surface phenomena associated with suspended particles, their affinities for different chemicals, and their use as substrates for microorganisms.
4. The determination of the qualitative and quantitative penetration of different kinds of light in relation to the kinds and sizes of suspended materials.
5. The determination of the light requirements of plants, both quantitatively and qualitatively.
6. Development of methods for determining the physiological effects on fishes and aquatic invertebrates of long exposure to high turbidities. Laboratory studies are needed to determine tolerable levels of turbidity or suspended materials for different groups of aquatic organisms such as phytoplankton and zooplankton, molluscs, aquatic insects (especially the Plecoptera, Emphemeroptera, Trichoptera, and Diptera) and effects on their productivity.
7. Laboratory studies to determine the effects of turbidity on migration of organisms and its influence on flow-drift of organisms.

The effects of settling materials on the bottom have been studied to some extent, but much more information is needed on the direct and indirect effects of turbidity on species available for food or recreation. Laboratory and field studies are needed to determine the effects of sediments on aquatic organisms and the amounts of these materials which are detrimental. Studies are needed to indicate specific effects of these materials and measures or indexes of tolerable limits.

Color and Transparency

Research is needed to determine the long-term biological effects of 25, 50 and 100 units of color derived from different sources on the growth and reproduction of phytoplankton, zooplankton, benthic organisms, and submersed plants. Information is needed on the extent to which a particular color affects the amount of light received at a given depth. Studies should be made on the biological consequences of color independent of the direct biochemical effects of the products inducing the color.

Salinity

Emphasis should be placed on the physico-chemical properties of seawater. Research is needed to determine the tolerable and favorable ranges of salinity for important organisms and the variable toxicity of pollutants at various levels of salinity.

There is still much to be learned about the physiology and behavior of estuarine animals or amphibiotic organisms migrating through estuaries. How do they regulate their internal environment under the radical changes of salinity? What are the energy requirements under different combinations of the varying characteristics of estuaries and how do the organisms meet these requirements? How do pollutants affect animal resistance when combined with euryhaline migrations? How can the animal survive the added burdens offered by pollution?

pH

Some of the general effects of pH changes on other environmental requirements and on the toxicity of materials and wastes are known, but much remains to be learned concerning the pH ranges which are tolerable and favorable for a large number of species. Data are needed on the specific requirements of the various organisms and the limits--upper and lower--of pH which affect them adversely or are lethal. More study is needed on the effects of pH on toxicity, oxygen requirements, tolerable carbon dioxide levels, and the availability and utilization of nutrients.

Temperature

Problems of temperature and dissolved oxygen are interrelated and should be considered as interdependent variables. Research on the following points is urgently needed: Do daily fluctuations in temperature have any biological significance? How rapid can the change be in either direction? Does it matter if the fluctuations are out of phase with the natural cycle? What are the relative effects of wide fluctuations above a daily mean? How much variation can incubating eggs withstand?

Information is also needed on the effects of seasonal fluctuations. Are seasonal fluctuations essential? How important are they in triggering spawning? Are they required for successful incubation of the eggs? Do they affect availability of food organisms? There is need to know how much of a temperature shock fish and other important aquatic organisms can withstand if swept into plumes of heated effluents, or if fish, especially amhibiotic forms, avoid areas of unfavorably high temperature. There is need to determine the transition in temperature that migrating fish can tolerate.

Another outstanding problem is that of the selective favoring of species by changes in temperatures and thus altering or nullifying an endemic balance of species. There is need to know the levels of temperature which are tolerable and favorable for all important species in the aquatic environment, marine, estuarine, and freshwater. At what temperatures will desired species be replaced by undesirable competitors? As temperatures increase, what are the trade-offs relative to increased growth and total productivity versus parasites, disease, shifts in species composition, and overall mortality? Information is required on the levels of temperatures which are tolerable and favorable for all important species in the different aquatic environments. Data are required on the specific effects of high, but sublethal temperatures; the duration of elevated temperatures which may become lethal, those which are detrimental and those which favor optimal development. Studies should be carried out to determine the ability of organisms to withstand long periods of high sublethal temperatures which extend beyond the normal summer period. Data are needed on the low temperature requirements of important organisms and the effects of these low temperatures on the development of sex products and the completion of the normal life cycle.

Studies are needed to determine if the acute or chronic effects of sublethal, high temperatures become more harmful when compounded with stress, such as toxicants, starvation, or salinity changes. Information is urgently needed on the temperature requirements for spawning, egg, and larval development of all species important for recreational, commercial, and forage purposes. Analysis of the behavioral and physiological mechanisms resulting in a particular performance should reveal some of the basic effects of temperature. Thermal tolerance diagrams are also needed for a larger number of the economically important freshwater anadromous fishes. Temperature-selection curves and temperature-activity curves are required for most if not all important species.

Oxygen

While a considerable number of studies have been carried out to determine the minimum dissolved oxygen concentrations required by certain species, a great deal of research is needed to determine the dissolved oxygen concentrations tolerable and favorable for all important species. The effects of low as well as high oxygen concentrations should be investigated. The effects of various continued levels of dissolved oxygen on growth rate, as well as the effects of periodically induced variations in oxygen content, and short-term exposures to low or high concentrations of dissolved oxygen should be determined. The metabolic rates measured as oxygen consumption by certain important species under various conditions of temperature and salinity of the water should also be evaluated. Tests should be conducted under controlled conditions, in properly designed and constructed metabolic chambers. It is desirable that each test be conducted for significant periods of time to obtain accurate levels of basal metabolism. Carbon dioxide produced during the test should be measured to obtain the respiratory quotient values (RQ). Effects of toxicants on metabolic rates, oxygen requirements and RQ should be studied using the important species for which controlled measurements have been previously obtained. Studies are needed to determine the oxygen requirements for the fertilization and development of eggs, development and growth of larval and juvenile forms as well as the effects of dissolved oxygen on the activity and reproductive cycle of the adults.

Carbon Dioxide

Information is needed on the levels of carbon dioxide which are tolerated for short or extended periods by various organisms and levels which do not produce unfavorable effects under conditions of long-term exposure. Information is needed on the photosynthetic needs for carbon dioxide. Buffer systems that are able to insure desired productivity should be developed. Buffering systems essential to insure desired productivity should be developed to promote desired growth. Extensive research is needed for determining the concentration of nutrients which produce undesirable blooms.

Nutrients and Nuisance Growths

Some of the factors contributing to excessive growth are known; however, concentrations and relative proportions of fertilizing material and other environmental factors essential to the production of undesirable blooms are unknown. Laboratory experiments can help define the conditions which promote these blooms in nature. In carrying out such studies, experiments of graded complexity can proceed from controlled laboratory experiments towards the sum of variables and the near duplication of the natural environment. Eventually, experiments should be carried out in controlled sections of natural streams, or in artificial streams, lakes, reservoirs, and estuaries to duplicate natural conditions. In this way, it would be possible to study specific chemical and physical factors as they affect particular species living in a complex ecosystem, as well as the effects of such factors on predator-prey relationships. Questions to be answered by research are, to name a few:

1. How are nutrient balances affected by the addition of given chemicals, under the influence of various day lengths, pH, temperatures, etc.?

2. How do shifts in nutrient balance affect the abundance of diatoms, blue-green algae, green algae and rooted aquatics?
3. How do these shifts affect the abundance of species which have high or low food values?
4. What species are the preferred food for the important organisms in the ecosystem?
5. Is a diversified diet of many species (diatoms and some green algae species) a better source of nutrition than a single species source?
6. As the human population and its organic waste continue to increase, how can nutrients be balanced or treated to promote desirable growths rather than nuisance blooms?
7. What are the best methods for removing nutrients from water and for the control of eutrophication?
8. How can mineralized wastes and sludges be used productively?
9. What kinds of bacteria and fungi are important in assimilating wastes in rivers and what environmental factors stimulate their development and the effective conversion of wastes to harmless materials?
10. How can the heat discharged in an effluent be used with beneficial effects or with minimized harmful effects?
11. What are the degrees of interdependence among species of groups? Studies on the effects of limiting species diversity could aid in this.
12. Which are the most important organisms in the food web?
13. Is energy more efficiently transferred through a high or low diversity of species within a food web?
14. How can our rivers be managed so that the shallow water areas support desirable aquatic organisms?

TOXIC AND DAMAGING MATERIALS

General

Largely due to the activities of man, many toxic materials are already present in the aquatic environment. The number is increasing continually due to the proliferation of new materials and industrial development. There already exists a great backlog of materials for which the acute toxicity to aquatic organisms should be determined. An even greater task is the determination of the long-term effects of these materials. While short-term bioassays have indicated the acute toxicity of several wastes to a few aquatic organisms, there is little information on concentrations of these materials which are chronically harmless to aquatic organisms of recreational, economic, and forage importance. Safe levels of these materials must be determined for all important sensitive species if the biota is to be protected. Information is lacking also on the possible antagonistic or synergistic effects of combinations of these materials on selected species.

Tastes and Odors: There are a number of materials which may, at sublethal concentrations, taint fish flesh, or produce odors and tastes which are undesirable. Studies are needed to determine those materials and organisms that produce tastes and odors in water supplies, as well as methods for their elimination on control. Studies should be carried out to determine materials that taint flesh of aquatic organisms; the length of time required for tainting; the maximum concentrations of these tainting substances which do not produce tastes or odors; and the time needed to render the tainted organisms for use.

Oils

Studies should be conducted at sites of oil pollution to determine

1. Chemical composition of oil slicks at their point of orgin and at increasing distances from it and the composition of oil sludges and their change in relation to time and distance from the spillage source.
2. Accumulation of water soluble toxic compounds in oil polluted waters, identification of them, and determination of their toxicity.
3. Rate of degradation of oil under controlled laboratory conditions and in the natural environment with special emphasis on the effects of oxidation on oil toxicity.

4. Gas formation in oil sludges, its identification and the carrying capacity of gas bubbles in moving or transporting oil to the surface to form new oil slicks.
5. Interaction of various water soluble fractions of oil with the organic compounds naturally present in the water.

Studies should also be made to determine the following:

1. The survival of adults, larvae, and eggs of selected species in different concentrations of various grades of crude oil, fuel oil and kerosene.
2. Effects of oil accumulation on the gas exchange apparatus of gill-breathing organisms. Aquatic insects, oysters, soft-shell clams, bay scallops, flounders, etc. are of interest here.

The following problems should be investigated in the coming years:

1. Anatomical injuries to fishes and other aquatic animals resulting from explosives used for oil exploration and other purposes.
2. Effects of explosions on behavior of individual animals, school formation, and stock migration.
3. Effects of vibrations on behavior of individual fish and other animals and on populations of important species.
4. Effects of vibrations on spawning, fertilization of eggs, and egg development.
5. Effects of explosions and vibrations on plankton.

Highly Toxic Wastes

Most of the studies on the toxicity of various materials to aquatic organisms have been short-term bioassays with pure compounds. While a few studies on complex wastes have been made, they have been limited due to the nature of the tests and the inability to secure large amounts of these wastes. Recently, a number of long-term studies have been made where low concentrations of toxicants have been maintained over the entire life cycle of a test organism. These relatively few observations have indicated that the application factor to be applied to TL_m values to denote safe concentrations during continuous exposure may range from 1/7 to 1/500 of the 96-hour TL_m. Application factors recommended by the National Technical Advisory Subcommittee on Water Quality Requirements for Fish, Other Aquatic Life and Wildlife are 1/10, 1/20, and 1/100 of the 96-hour TL_m. It was realized that in certain instances these factors would be either overprotective or possibly inadequate. Newly-determined application factors should replace these interim values as rapidly as scientific observations are completed. Research to determine application factors for the most important wastes is imperative.

The following research projects involving studies on highly toxic wastes, should be given priority for adequate protection of aquatic life.

1. Development of methods for raising all life stages of test organisms in order to complete essential laboratory bioassay studies.
2. Short-term bioassay studies to identify the most sensitive species and the most sensitive life stage to selected materials and wastes.
3. Long-term bioassay studies with those species and life stages which are the most sensitive to a particular waste to determine the following:
    a. The consequential effects of non-lethal damage at any stage on successive stages in the life history.
    b. The effects on all life stages of sublethal exposures during the most sensitive stage.
    c. Comparative studies of the effects of exposure during the most sensitive stages and of exposures during the entire life-cycle.
4. Determination of the normal range of natural environmental fluctuations on the toxicity of various materials.
5. Associated with investigation of the long-term effects of various toxicants, the following studies should be made.
    a. Determination of the mode action, of toxicants, their metabolites, and detoxification mechanisms.
    b. Determination of the interaction of two

or more toxicants; synergistic and antagonistic effects, and those materials with similar and different modes of action.

6. Studies should be initiated to develop short-term methods for determining long-term effects. These studies should include the following.
   a. Behavioral studies to detect any change that may render the organism unable to cope with the natural environment or make it susceptible to predation or disease.
   b. Physiological studies to detect any adverse functional effects of exposure to sublethal concentrations of toxicants.
   c. Investigations of effects on enzyme or endocrine gland functions.
   d. Metabolic studies evaluating changes due to the action of toxic materials.
   e. Blood studies for the development of methods that may indicate subtle sublethal effects.
   f. Histological, histochemical, and histopathological studies to detect changes due to sublethal concentrations of toxicants.
   g. Use and adoption of methods developed by medical science for the detection of toxicants and the evaluation of their effects.
7. Bioassay experiments should be designed to permit adequate statistical analysis of the results. Reliable formulae for the computation of application factors could thus be derived.
8. Bioassay methods are needed for arthropods, molluscs, worms, phytoplankton, zooplankton, and bacteria. Studies are needed for improvement and standardization of bioassay procedures; for the utilization, development, adoption, and improvement of bioassay instrumentation; for the monitoring and control of water quality and for the detection and the measurement of pollutants.
9. Research is needed to determine the toxicity of degradable toxic products and to determine the

mechanism and rate of their degradation.

Radioactive Wastes

Research is needed for determining the following:

1. Behavior and fate of radionuclides in the aquatic environment and their concentration by aquatic food organisms.
2. The influcence of the physico-chemical state of the radionuclides and the characteristics of the dynamic equilibrium within the ecosystem on the availability of the radionuclides to the biota.
3. The effects of environmental conditions upon the biological concentration of radionuclides and their passage through food chains.
4. The damaging effects of the continuous exposure of sensitive stages of important aquatic organisms to radionuclides.

ECOLOGICAL FIELD INVESTIGATIONS

Although laboratory experiments can provide valuable information on how an organism reacts under controlled conditions, they do not necessarily reveal how an organism will react under the stresses found within the complex ecosystems of natural waters. There are many instances where the predictive values of such laboratory experiments are poor. This is probably due in great measure to the largely artificial environment in which they are carried out. Therefore, some of these experiments should be extended to areas duplicating natural environments, such as pilot areas or areas in sections of natural waters which can be monitored or controlled for the purposes of these studies. Ecological field studies are needed to evaluate laboratory findings for the favorable ranges of such environmental factors as temperature, dissolved oxygen, carbon dioxide, dissolved solids, suspended solids, setteable solids, turbidity, color, light requirements, currents, salinity, and pH.

Methods

Available field methods are not adequate to meet the problems which we now face in the detection and measurement of various environmental factors and their effects on the aquatic biota. There is a need to develop facilities, equipment, and methods for field testing so that necessary studies can be carried out under natural conditions for determining harmful or favorable effects. Better sampling methods are needed for both grab samples and continuous monitoring. More accurate methods for compositing samples and taking samples from composites should be developed. Better instrumentation is needed for continuous recording of environmental factors. Better methods or models are needed for relating the conditions in streams, lakes, reservoirs, estuaries, or coastal areas to various kinds of land use and to various kinds and amounts of effluents being discharged into these waters. To improve the evaluation of sublethal or obscure effects of potential toxicants, more precise field methods are needed for determining the effects of pollution on the ecosystem and for measuring standing crops and productivity at the various trophic levels. Autopsy techniques should be developed for determining the cause of kills, the concentrations of the toxicants or their metabolites in the organism, and the relationship of these compounds to lethal or sublethal effects.

Environmental Requirements

Temperature: Field studies on the effects of heat are necessary under pilot plant conditions or in the environment where conditions are the same or as nearly approaching natural conditions as possible. Ecological observations should be conducted in the areas affected by discharges of heated water from power plants. Experiments conducted in tanks, troughs, or raceways under controlled conditions should be carried out to determine the survival of species studied. These studies should include effects of temperature and its variations on the competition of the different species, the effects of extremes in temperature and temperature variations on the movement of aquatic organisms, their spawning, egg development and survival, development of larvae, the presence of growth anomalies, and the production of desired species.

Dissolved Oxygen: Field studies are needed to determine oxygen concentrations which are lethal, or unfavorable, and those which are favorable under natural conditions where there is competition for food and space, and where the other stresses found in a natural environment are present. Such studies are needed for fresh, estuarine, and marine waters. Much can be learned by field ecological studies of the occurrence and well being of populations of important species in waters with normal as well as different oxygen concentrations and different daily and seasonal variations.

Toxic Materials: Special pilot study areas, controlled natural areas, or natural areas must be used for the field evaluation of laboratory findings on toxicity. Natural areas may also eventually be used for determining the effects of a toxic material or waste on the entire biota of a water.

The direct translation of laboratory data to the field situation is very difficult and often unsatisfactory. Under natural conditions, there may be a rapid reduction in the concentration of a toxicant by one or more of the following: precipitation, adsorption on soils and bottom materials; chemical decomposition; reactions with other substances in the water; absorption by microscopic organisms; removal by organisms and biochemical degradation. Accumulation of these materials in the food chain and ingestion of food organisms bearing relatively high concentrations of these materials may increase the exposure to the higher organisms.

Laboratory findings on the safe levels of potential toxicants and environmental requirements must be field tested under conditions where the organisms in question are exposed to all the stresses occurring in the natural environment. Such tests should be carried out before water quality requirements are recommended. When developed, tested, and evaluated, field studies can be used for simultaneously testing all the species in the biota under natural conditions. In such studies, biological magnification, storage, passage through the food chain, accumulation in bottom materials, competition for food, cover and living space, the effects of disease parasites and predators, synergism, antagonism, and the interaction of materials and all other complicating factors present in the natural environment are taken into consideration. When effective studies can be made in streams, lakes, reservoirs, estuaries, and coastal areas, the determination of safe levels of potential toxicants in the environment will be made in much less time. Such field studies will require development of improved methods for estimating the biota and seasonal changes in the biota, as well as development of analytical methods for continually monitoring the actual consideration of potential toxicants in the areas under test. Where known pollutants occur and fishery statistics are available, field studies properly designed and carried out can be the most convincing means of determining effects of such pollutants. A great deal can be learned by evaluating the effects of nature's bioassay; i.e., evaluating the biota that has developed and maintained itself under certain environmental conditions. Observations of populations and population dynamics, in different areas having different levels of wastes, can be very informative in indicating relative sensitivity and the overall effects upon the biota of the additions of these wastes.

WILDLIFE

The needs for wildlife are largely met if the requirements for aquatic life are satisfied. However, additional research is needed for the determination of special requirements essential to wildlife. The following research studies should be expanded to determine:

1. Distribution of pesticides, heavy metals, and trace elements in the wildlife food chain and the tissues of various species, expecially migratory birds.
2. Analytical methods to differentiate between the compounds present in the environment versus the absolute amount of compounds available for absorption by plants and animals; e.g. Hg and Se.
3. The plants and animals that concentrate specific chemicals to levels capable of intoxicating other organisms in the food chain. Elements of toxic significance are antimony, arsenic, beryllium, bismuth, cadmium, chromium, lead, lithium, mercury, nickel, selenium, silver, tillurium, and thallium.
4. In addition, studies should be made on the effects of environmental nutrient elements present

in excessive amounts or in deleterious combinations. Among these are barium, boron, calcium, cobalt, copper, iron, manganese, magnesium, molybdenum, potassium, sodium, and zinc.

5. New or better analytical methods for identification and quantitation of nutrients, toxicants, and trace elements, their movement through the food chain, their biological magnification, and where, when, and in what form they accumulate.

AGRICULTURAL WATER SUPPLIES

INTRODUCTION

The report of the National Technical Advisory Committee on Water Quality Criteria for Agriculture points out the lack of adequate, well-qualified research data for developing satisfactory water quality use criteria. It is also apparent that it is difficult to divorce certain aspects of use criteria from water pollution and water quality control.

Problem-oriented research is necessary to supply the information needed for correcting deficiencies listed in the report. Furthermore, since pollution abatement is so closely associated with use requirements, coordinated research efforts should be encouraged to supply the information necessary for effective water quality control. The rapid changes occurring in agricultural and industrial technology demand that an on-going research program be maintained to provide solutions for new problems as they arise.

The accompanying list of research needs is designed to correct deficiencies in existing knowledge of water quality in relation to agriculture As indicated above, these needs are not restricted to water use requirements, but include other related factors such as pollution control and water management. Although research is currently in progress in some of the areas listed, the effort should be considerably strengthened. Research should be done by those most competent in the field.

The items listed here are relatively general and each could be broken down into more specific areas of research. No priority has been assigned to these items due to lack of time in preparing this report but this should be a definite consideration. The intent of this report is primarily to point out those areas where additional information is needed in the field of water quality.

GENERAL

The following research needs are related to general problems involving water use by agriculture. They are not related to any specific use but deal with the evaluation and optimization of water quality in existing water resources.

1. There is a great need for the development of improved procedures for rapidly evaluating water quality for agricultural uses. This should emphasize trace elements, exotic organic compounds such as pesticides, and certain pathogenic and nonpathogenic microorganisms. Water quality for a specific use must be determined at the time the water is to be used to be most effective. Results of this research would provide methodology for this purpose.

2. Better methods are needed to monitor waters for agricultural purposes. New or improved sampling procedures are needed which relate more accurately to time and flow variables including sample preservation techniques. New or improved instrumentation must also be developed for many of the important parameters such as pesticides, sediment, and certain trace elements. A particularly difficult problem is posed by pollutants adsorbed to soil that is subsequently washed into a waterway. Research into these problems must be a continuing effort to insure the highest level of proficiency concomitant with the latest technology.

3. There is a great need for current data on the quality of our water resources. Existing water quality surveys and monitoring programs should be expanded on a systemized basis to provide the basic data required for developing improved water quality management practices. Since it is impractical to measure all water quality parameters at all sampling sites, careful study and consideration must be given to the selection and significance of the parameters to be measured. Systems should be designed to have pollution surveillance potential and a built-in mechanism for alerting users of any potential hazard.

4. Research is needed to develop more significant indicators of water quality. An example of this is in the area of microbial pollution of waters. Existing use of coliform density is recognized as inadequate. Studies are needed on the ratio of the number of coliforms, fecal coli, and fecal streptococci as possible indicators of the number of salmonella, shigella and other animal and human pathogens in water. The fecal streptococci are of particular interest as they apparently do not multiply in water even at warm temperatures.

5. Lakes, reservoirs and other impoundments constitute a major source of water for agricultural and other uses. Research is needed to develop improved management practices for water quality control in these resources. Potential effects of soil and site preparation on reservoir water quality should be determined. Heat budgets in impoundments also should be evaluated as a guide to possible control of algae, evaporation, and other quality considerations. This would include the development and evaluation of new evaporation retardants and their effects on various physical, chemical, and biological parameters. A study should be made of the physical and chemical stratification in impoundments as they relate to dissolved oxygen budgets, iron and manganese cycles, and other environmental factors. Much more information is needed to determine the basic processes of eutrophication in small and large impoundments, especially with regard to nutrient requirements for various types of desirable and undesirable aquatic plant growth. The effect on water quality of various materials adsorbed to sediments must be evaluated in respect to their significance for various uses. Techniques must be developed for predicting effects of proposed reservoirs on downstream water quality.

6. Socio-economic factors related to various uses must be taken into consideration in setting legal standards. Economic surveys must be initiated which would take into account existing conditions, pollution abatement costs, water treatment costs for various

uses, and resulting potential economic effects on various water uses. Procedures must be developed to take into consideration cost-benefit studies involving multiple objectives and multilevel decision-making frameworks. Such surveys would indicate areas where more detailed study is required to solve specific problems or offer acceptable alternatives.

The above listed research needs are directly related to agricultural requirements, but are also applicable to water resources in general. The research needs that follow are directed towards those problems relating to water quality for various agricultural uses and water quality problems resulting from agricultural operations.

WATER QUALITY FOR AGRICULTURAL USES

Farmstead Water Supplies

The need for additional water for farmstead uses has brought about the utilization of water which, although plentiful, usually requires treatment to remove or control undesirable physical, chemical and bacteriological contaminants. The demand for water will continue to increase and more sources requiring treatment will have to be used to meet future needs. Research is needed to develop and evaluate criteria for various uses.

1. Equipment and controls for water purification should be developed for better utilization of available water supplies. Methods should also be found to permit constant monitoring of the effectiveness of water treating equipment.

2. Certain organisms found in water are very resistant to all known types of chemical disinfection. Ultraviolet irradiation and heat treatments have been suggested as alternative methods for the control of those organisms resistant to chlorine. Research should be conducted:

   a. To determine the nature of resistance of micro-organisms to chlorine including time vs concentration relationships involved;

b. To determine whether ultraviolet irradiation and heat treatments are effective in destroying all organisms potentially troublesome in water used in milkhouse sanitation;

c. To develop improved methods applicable to farmstead operations for controlling resistant organisms.

3. Automated cleaning systems have become a major need on farms, creating both a water supply and waste disposal problem. Information is needed to develop water conserving methods but still assure proper sanitation in milkhouse, household, and product marketing operations.

4. The influence of water quality on sanitation efficiency has not received enough attention. Information is needed to determine the influence of water supplies of various compositions on the efficiency of sanitation procedures and chemicals.

5. Corrosive waters remove metal ions from piping materials and cause them to be deposited on milk contact surfaces during recirculating cleaning operations. This results in flavor deterioration of the product. The relationship of piping materials to water composition should be studied and pipes and fittings developed which are not affected by corrosive waters.

6. Ponds, wells, and cisterns are subject to pollution from various sources. Information is needed regarding the significance of specific pollutants for various farmstead uses and the development of remedial measures. Emphasis is placed on bacterial and viral contamination of these waters.

7. Many states have adopted different requirements governing the use of pond and cistern water. Basic requirements should be determined for such

water supplies and these requirements should be acceptable to responsible agencies so that farmers in different states shipping milk to the same market can operate under comparable regulations.

8. Rapid methods for assessing microbiological contamination in both treated and untreated water are urgently needed. Non-cultural techniques for total bacteria count and refinement of these methods to include specific organisms should be developed. Another aspect of evaluating fecal pollution would be to explore non-bacterial indicators which would assess not only the degree of fecal contamination but also the stage of degradation.

9. Increasing quantities of water will be used for washing and hydrocooling raw agricultural products on the farm prior to processing or marketing. Studies should be conducted to determine the basic water quality criteria necessary for such uses and practical treatment procedures that may be employed to achieve these criteria. Particular attention should be given to human pathogens in water used to wash or hydrocool agricultural products.

Water for Livestock

Research needs in establishing water quality criteria for livestock are intimately related to satisfactory quality in the raw state, as well as after treatment. Water consumed by livestock usually satisfies their need for a positive water balance, without regard for substances in solution or suspension which may enhance or adversely affect health.

1. Systematic accumulation of information on water quality for livestock uses is related to a number of parameters, including geographic location, source (rainfall, surface, deep well), soil types, proximity to known sources of contamination, temperature, etc. A survey approach designed to identify the qualitative aspects of contamination of livestock water supplies is needed. It would be convenient to subdivide the contaminants into organic and inorganic components. Conceivably, this approach could lead to a cooperative

effort among a number of sites, perhaps chosen on the basis of representing specific areas of water contamination. The result of organized surveys of the type proposed would be a more accurate identification of the specific nature of livestock water problems than is presently available.

2. Specific data on tolerance levels by various species of domestic animals for the various contaminants identified in (1) should be obtained. This approach is a logical extension of the data gathered on the occurrence of the various inorganic and organic contaminants. It is complicated by the relationship of both qualitative and quantitative aspects of dry matter to water consumption by the animals in question. In other words, careful attention must be paid to feed intake criteria in establishing the effects of aqueous contaminants. While some general criteria might be established with laboratory animals, species differences will likely dictate that most of this work be conducted with domestic types.

3. The mode of action for toxic contaminants in livestock water supplies should be established. Once the incidence and overall systemic affect of contaminants has been identified (1 and 2 above), information of a basic biochemical and physiological nature concerning their mode of action would be most valuable. In some cases, this information would relate to species differences; e.g., it seems likely that changes due to metabolic activity in the rumen might exert significant effects upon certain water contaminants consumed by cattle and sheep.

4. Research to establish the limits of tolerance for dissolved solids which may appear as normal constituents in water must take into account the interaction of the various elements and compounds. Ecological considerations indicate that laboratory and field results may be in such variation as to have limited value. It is seldom that the type of food consumed can be separated from water consumed, as both influence the well-being of the animal. The

physiological effects of satisfactory, tolerated and intolerable limits of dissolved solids which normally occur in water are known. There appears to be a real need, however, to study the effects of specific pollutants which may occur in water and their interactions in animal metabolism.

5. Objectionable compounds occurring in livestock drinking water as a result of agricultural and industrial activities can be a principal threat when the livestock enter a food chain including man. Research is needed to assess the role of water-borne sources of these compounds as compared to food and other environmental sources. A distinction should be made between toxic effects and mere biological accumulation in animal tissues. Even though the polluting substance may have no measurable effect on animal health, its presence in water may result in a tissue excess which could make the animal products unmarketable.

6. Development of satisfactory methodology for testing and monitoring livestock water supplies and for testing animal responses to such supplies is necessary since adequate methodology does not now exist. Two distinct areas are involved in this approach:

a. That of research methodology where techniques are developed, checked, and approved, and

b. That of application, on the farm or ranch, particularly for monitoring purposes.

The latter type of methodology will involve additional requirements for facility of operation, speed of determination, and economy, in addition to the criteria of accuracy established by research.

7. Additional planning and developing economically efficient processes of water purification for livestock uses is greatly needed. Although highly efficient water purification processes are available, generally they have

been devised for industrial use or for treating water for human consumption. There are sufficient differences in the flow characteristics and the cost factors involved with livestock water supplies to justify specific research in this important area.

8. An investigation might be made of processes by which water contaminant sources could be diverted to useful purposes. Obviously, one of the major obstacles in accomplishing the purification desired in water supplies for livestock is cost. Net cost might be significantly reduced if the purification process were to yield some useful product. Areas of potential interest include the harvesting of algal growths for nutritional purposes. In connection with this, separation of certain contaminating wastes (such as sulphite liquor) for use in a medium that might support microfloral growth and the elimination of inorganic contaminants from water (perhaps by ion exchange) so that they might be used for other purposes should be investigated.

9. Fundamental information concerning all aspects of the problems concerning contamination of livestock water supplies should be systematically assembled and analyzed. There will doubtless be a host of ancillary problems which would require the assembly of basic facts and principles which are presently unavailable.

Water for Irrigation

Salinity is a major water quality consideration in irrigation agriculture. Dissolved solids in irrigation water can severely deter plant growth and, under certain conditions, have an adverse effect on soil structure. Research needs listed below relate only to irrigation use aspects. Salinity levels in irrigation return flows generally indicate a degree of quality degradation and should be taken into account in assessing water use criteria.

1. Plants are known to vary in salt tolerance. Research is needed to evaluate the nature of salt tolerance in plants and to develop new plant varieties or species having greater tolerance to soil salinity and alkalinity. This requires more

detailed information on the physiological and biochemical processes going on in plants growing under saline conditions.

2. More information is needed on soil-plant-water interactions relating to plants grown on a saline substrate. This would be a systems approach to integrate the effects of the various inputs. This is extremely important since a major effect of salinity relates to the osmotic regime in the plant. It involves water movement in the soil to the plant roots, uptake by the plant, movement of water and translocation of nutrients within the plant, and transpiration of water from the plant. Since plants are more sensitive to salinity in certain growth stages, this factor must also be taken into consideration. An understanding of these interrelated factors is essential in determining the level of salinity which can be tolerated in irrigation water.

3. Specific soil characteristics determine, to a degree, the level and type of salinity that can be tolerated in irrigation water. Since there are a multitude of different soil types in irrigated areas, the chemistry and mineralogy of these soils must be evaluated to determine the effect of waters varying widely in composition on the chemical and physical properties of the different soils. Information obtained can then be used to develop much needed predictive relations.

4. The salt content of a soil is determined by the salt content of the irrigation water applied, that initially present in the soil, the rate of water lost by evapotranspiration, and the adequacy of drainage. There is a great need for more information regarding factors affecting the movement of salts in soil water both in the saturated and unsaturated state. This knowledge is necessary to develop guidelines for determining the quantity of irrigation water to be applied to minimize salt accumulations.

5. Climatic conditions and management practices influence the level of salinity that can be tolerated in irrigation water. Research is needed to evaluate these relationships so that more effective guidelines can be developed to make more effective use of saline irrigation water.

6. Increasing demands on existing water resources suggest that some day desalinated water may be used for agriculture. On soils currently being irrigated successfully with water containing relatively high amounts of salts, use of desalinated water may create new problems. Research is needed to determine potential problems and means for circumventing them.

7. Utilization of saline irrigation water can create an unfavorable nutrient balance in the soil solution. Research is needed to accurately predict these affects and the resultant effects on plant growth and to develop corrective measures where feasible.

8. In view of the many factors involved in determining the level of salinity that can be tolerated in irrigation water, a systems approach is needed to develop predictive soil-plant-water relationships concerning the quality of water that can be used for irrigation and the quality of water returned to the source as drainage.

9. Attention has been called to the balance of salts going on the land in irrigation water and the amount of salt leaving as surface return flow or finding its way into ground water. There is a need for improved techniques using systems analysis to assess the salt balance within a river basin. Once a suitable technique has been developed, it should be applied to assess the salt balance of the various river basins in the western United States.

Trace elements can find their way into irrigation water in many ways. Some are inherent in soils and geologic formations. Boron is a good example of this. Acid mine drainage may be a source of toxic concentrations of heavy metals. Pollution of water resources by industry can give rise to a wide variety of trace elements, many of which are seldom considered in plant nutrition. To evaluate the potential impact of trace element pollution on irrigation agriculture, several areas of research should be explored.

1. Trace elements added to soils through irrigation water may be fixed and rendered unavailable to plants or they may remain in an available form and subject to leaching. Research is needed to determine the reactions of various trace elements in the soil to determine the availability to the plant of compound formed and to evaluate the leachability of these trace element compounds from the soil. Interactions and cumulative effects of these trace elements must also be determined.

2. Trace elements can affect plants in two ways. At certain levels, they may be toxic and either deter growth or kill the plant. Other trace elements may not affect plant growth but may accumulate in plants in concentrations high enough to be detrimental to animals or humans consuming them. Research is needed to determine specific levels of plant tolerance for different trace elements with regard to both species and stage of growth. There is also a need to determine which elements, such as selenium, accumulate in plants and may be toxic to animals or humans consuming them. Here, again, specific information is needed with regard to species and toxic levels.

3. Research is needed to develop management practices to minimize hazards which may occur from trace elements applied in irrigation water. Corrective measures must also be developed to alleviate existing toxic conditions resulting from trace element accumulation in soils.

Little consideration has been given to the role of irrigation water in the transfer of plant, animal, and human pathogens. These pathogens may find their way into irrigation water in runoff from fields having diseased plants, from animal wastes, and from domestic sewage. Research on the following problems should include both laboratory and epidemiological studies.

1. It is believed that certain plant pathogens may be transmitted in irrigation water but little precise information is available. There is a great need for specific information concerning the potential spread of nematodes and bacterial, fungal, and viral diseases in irrigation water. An assessment should be made of both sprinkler and surface type irrigation practices. Factors affecting survival of various pathogens in water must also be evaluated. Along with methods of assaying water for plant pathogens, consideration should be given to the development of control measures to prevent contamination.

2. Specific studies are necessary to relate the incidence of human and animal pathogens in irrigation water to indicator organisms such as fecal coliforms and streptococci. This is of extreme importance where irrigation water may be contaminated by animal wastes or untreated sewage. Analytical methods should be developed where feasible to survey water for suspected pathogens.

3. Where sewage contaminated water is used for irrigation of crops, especially those to be consumed raw, research is needed to determine the incidence and survival of known pathogens. This is also true for animal pathogens on irrigated pastures. Hazards may result from pathogens retained on leaves or from those penetrating into roots and perhaps being translocated to the above ground portions of plants. Research is needed to determine the magnitude of this problem. There are many specific examples of potential problems but only a few will be mentioned here. Mycobacteria, including atypical groups, should be investigated on crops irrigated for livestock consumption. The extent of liver fluke infection in livestock fed on irrigated pastures should be assessed. An investigation should be made on the prevalence of snails

in irrigated areas which might act as intermediate hosts for schistosomes. Information is needed on the absorption, translocation, and survival of mammalian viruses in irrigated crops which may be consumed raw.

4. Research is needed on the economic impact of plant and animal pathogens occurring in irrigation water. This should include the economics of potential water treatment methods.

5. Research is needed on control of plant pathogens in infected irrigated areas. Once it has been established that soil in an area has become infected with a pathogen from irrigation water, specific corrective measures will be needed to insure elimination of the hazard for continued safe use of the land.

6. Surveillance procedures should be developed and evaluated to prevent the spread of pathogens carried in irrigation or drainage water.

Pesticides have received considerable attention as potential soil and water pollutants. Current information is inadequate to evaluate properly the extent to which this is a problem. Regarding pesticides in irrigation water, there are several aspects requiring additional research. Since pesticides vary considerably in chemical composition, individual pesticides or groups of pesticides should be studied separately.

1. There is a need for more information on the fate and behavior of pesticides in water. This is especially true for herbicides applied to water to control aquatic weeds in irrigation and drainage systems. In a water system, diffusion, chemical reaction, photodecomposition and leaching through seepage must be investigated for specific pesticides. Pesticides occurring in the free and adsorbed states should be evaluated separately.

2. Additional information is required on the degree to which pesticides are leached from soils and find their way into ground waters and the degree to which they

persist in surface irrigation return flows either adsorbed on soil particles or in solution.

3. Research is needed on tolerance of different crops to aquatic herbicides applied in irrigation water.

4. Insecticide solubility in water is relatively low but that for certain herbicides may be high enough to cause problems. In areas where either of these could present a problem, research is needed to determine the degree and persistence of water-applied pesticides in soils and the physical, chemical, and biological processes involved. Plant research is also necessary to determine the degree to which pesticides may accumulate in plants and become a potential hazard to animals or humans consuming them.

5. Emphasis should be placed on the development of more readily degradable pesticides for agricultural usage in water which will not adversely affect water use for other purposes.

Sediment is considered to be the number one pollutant. We are well aware of its impact on our streams, rivers, and impoundments. Aside from reducing the storage capacities of impoundments and altering stream channels, sediment in irrigation water creates additional problems.

1. Research is needed to develop criteria for improved engineering design of sediment traps and debris basins. Increased knowledge of the mechanics of sediment transport is required to provide design criteria for the maintenance of stable stream channel systems and for the development of more economical and effective methods for stream bank stabilization.

2. Additional information is required regarding the mechanics of sediment transport in irrigation systems. Although somewhat similar to that in streams, specific methods and design criteria

are needed to prevent loss in carrying capacity and degradation of irrigation systems.

3. Although it is known that suspended sediment in irrigation water can plug or damage sprinkler nozzles and pumps, no specific information is available regarding the sediment concentration and particle size distribution required to produce damage to pumps and sprinkler equipment. Meaningful criteria for water quality standards cannot be provided until such data is supplied.

4. Sprinkler irrigation water may frequently contain relatively large quantities of suspended colloidal material. During irrigation, a certain amount of this colloidal material is deposited on leaf surfaces. Research is needed to evaluate the effect on photosynthesis and other physiological processes of a colloidal coating on leaves. If significant, corrective measures should be developed.

5. Considerable sediment is often entrained in surface irrigation water. During irrigation, this material is deposited on the soil surface which may impede infiltration and cause crusting and cracking as the soil dries. There is a need for additional information regarding the interactive effects of particle size distribution, mineralogical content, adsorbed cations, and salt content on these factors. Results obtained could be utilized in determining management practices to minimize this hazard.

6. Research is needed to evaluate the role of sediment in the transport of pesticides and other agricultural chemicals in an adsorbed state. Information regarding particle size, mineralogical composition, and specific nature of the adsorbed pesticide on other constituents should be taken into consideration. The equilibria between chemicals adsorbed on sediment and those in solution should be evaluated in relation to their effect on various water uses.

Although there is no immediate problem of radioactive contamination of irrigation water, there is a possibility that this could occur as a result of accidental releases, drainage from uranium mines, nuclear testing, and perhaps nuclear warfare. Should any of these eventualities occur, information should be available to minimize radiation hazard.

1. Information is needed on foliar adsorption and absorption of radioactive materials when sprinkler irrigation is used. For surface irrigation, uptake and translocation of various radionuclides should be determined.

2. For irrigation water infiltrating the soil, research is needed to determine the degree to which radionuclides are leached from or retained in the soil as a function of soil physico-chemical characteristics, volume of water applied, and characteristics of specific radionuclides. Consideration should be given to potential accumulation of radionuclides in soils resulting from long, continued use of contaminated irrigation water.

3. Predictive relationships must be developed to integrate the above information and determine the health hazards which may result from radioactive contamination of edible plants by contaminated water and soil. Long and short term effects must be evaluated.

There are other water quality criteria which may be given consideration although they are not as significant as those listed previously.

1. Dissolved oxygen and BOD are parameters frequently appearing in the literature. It is questionable whether the dissolved oxygen in irrigation water would ever be low enough to inhibit plant growth. High BOD values in irrigation water, however, might adversely affect the oxygen level in the irrigated soil. This could readily occur in waters polluted by industrial effluents. Research is needed to evaluate various soil factors affecting the soil oxygen level resulting from use of high BOD waters and the resultant effect on plant growth. Should

reducing conditions develop in the soil, information is needed to determine whether iron and manganese may be reduced to the more soluble divalent state, thereby becoming toxic to the plant.

2. There is some evidence available to indicate that either extremely high or low temperatures of irrigation water might affect plant growth. Additional information is required on the temperature of irrigation waters from various sources to establish ranges that may be expected to occur. Investigations should be conducted to determine temperature changes occurring from point of source to point of application. In addition, information should be obtained on changes in soil temperature that occur when water of a given temperature is applied to a soil during different times of the day and the resulting effect on plant growth, if any.

3. Acidity in water, unless extreme, is not likely to adversely affect irrigated soils. Should extreme acidity occur as a result of contamination from acid mine drainage or industrial pollution, investigations should be initiated to determine soil mineralogical and chemical characteristics that would indicate potential problems from solubilization of aluminum, iron, and manganese. Problems arising from other trace elements and interactive affects should be included. Another aspect of acidity in irrigation water relates to corrosion of irrigation equipment. Information is needed regarding critical pH levels at which insignificant corrosion occurs in different metals used in pumps, irrigation pipes, and sprinklers.

WATER QUALITY PROBLEMS RELATED TO AGRICULTURAL PRACTICES

Agriculture's contribution to the water pollution problem is difficult to evaluate because of the lack of sound research data. Research needs described in the preceding section pertain to water quality for use by agriculture without regard to the source of the pollutant. Quality of our water resources may be affected by agricultural practices either directly as a result of irrigation, or indirectly through the influence of agricultural chemicals and animal wastes on seepage and runoff from agricultural watersheds. Wadleigh* has presented a comprehensive discussion of wastes in relation to agriculture including: (1) the effects of wastes on agriculture, (2) what wastes are contributed by agriculture, and (3) research needs relating to waste production and management. Some of the latter information, where applicable to water quality, will be included in the following discussion.

As stated in the introduction, no clear line can be drawn between problems relating to water use criteria and quality control. As a result, some of the items discussed in the previous section may be repeated here in part. Where this occurs, the repetition and emphasis is undoubtedly warranted.

Salinity

Salinity is a serious problem in irrigated agriculture in the Western United States. The salt content of water applied to fields is increased through evaporation and transpiration. Water returning to surface sources through return flows and drainage and that finding its way to ground water, usually has a higher salt content than the water added. Leaching for reclamation of saline and alkali soils also increases salinity in water resources.

1. One of the pressing needs for information in irrigation agriculture is the development and evaluation of procedures for disposal or reclamation of saline return flows. These procedures should seek to maximize beneficial use of total water available, while minimizing contamination for downstream users.

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*Wadleigh, C. H. "Wastes in Relation to Agriculture and Forestry" (unpublished)

2. Control of soil salinity is best accomplished by maintaining a favorable salt balance in the field through controlled leaching. There is a need for continuing research to develop improved mathematical expressions for the calculation of leaching and drainage requirements to insure efficient use of water with a minimum of pollution from increased salinity.

3. Salt composition as well as concentration can be altered by movement through the soil during irrigation. More information is required to predict and evaluate chemical changes which take place in irrigation water as it infiltrates the soil and returns in drainage or ground water and the resultant effect on the soil.

4. Widespread use of salt on highways for snow and ice removal frequently affects vegetation along highways and contaminates adjacent ground waters. Existing soil and water salinity research must be supplemented to find solutions for these problems. Alternative methods of snow and ice removal should be developed to minimize water contamination by chemicals used on highways.

5. To integrate the entire salinity problem, procedures should be developed for deriving a salt balance within a given watershed or river basin. Information thus obtained would be helpful for developing appropriate management and control methods.

Nutrients

Eutrophication of streams, lakes, and reservoirs is attributed to nutrient enrichment; the predominant problem results from an increase in nitrogen and phosphorus. Fertilizer and animal wastes are frequently cited as sources of these elements. The significance of the actual contribution of these materials from agricultural sources has yet to be adequately established.

1. The specific contribution of fertilizers and animal wastes to nitrogen and phosphorus content in water resources should be determined under

various management systems, climatic environments, and on representative soil types.

2. Phosphorus in water occurs in solution in both organic and inorganic forms, absorbed by sediments, and as a component part of the suspended material. Improved analytical procedures are needed to distinguish between these different forms of phosphorus and studies should be conducted to evaluate the relative contribution of each to the eutrophication problem.

3. Since phosphorus adsorbed on sediments probably constitutes a significant part of the problem, information is needed to determine the effects of turbulence and physico-chemical conditions in water on the equilibria between adsorbed phosphorus and that in solution.

Sediment

Sediment production results from the soil erosion process. Although much sediment originates from agricultural land, in recent years increased erosion from highway construction and suburban and industrial development has contributed greatly to the problem. The mechanics of erosion are the same, however, regardless of the source.

1. Increased research efforts are needed to understand the mechanics of erosion which include particle detachment by raindrop action and movement in flowing water. Effects of rainfall characteristics, soil structure, topography, water retention and transmission characteristics of soils, vegetative cover, and other related factors must be evaluated and integrated into predictive equations for estimating sediment delivery from different land use areas.

2. Land use and management practices must be developed for minimizing sediment production on a watershed basis. Predictive relations described above must be utilized in identifying the erosion potential of specific areas to develop corrective management practices.

3. Protective vegetative cover is a critical factor in controlling erosion. Establishment of a satisfactory cover is extremely difficult, however, on severely eroded lands, strip mine areas, roadbanks, construction areas, and other deteriorated sites where growing conditions are severe. Adequate revegetation may require the use of new plant species or strains which will survive and stabilize these areas. Soil treatments must be developed which will create a more favorable environment for the desired plants.

4. Once sediment finds its way into streams, processes of transportation and deposition become highly significant. More information is needed on the mechanics of sediment transportation under varying conditions of flow and turbulence. Additional research is needed on factors affecting stream channel stability and the development of economic methods for stream bank stabilization. In addition, improved criteria for the design of sediment traps and debris basins are needed.

5. The role of sediment as a transporting agent for residues of pesticides and other chemicals in stream flow must be more clearly defined.

Organic Wastes

Intensification of livestock farming has created a problem of animal waste disposal. Manure can no longer be economically used as a fertilizer and soil amendment in many areas. Concentrations of these wastes could result in both chemical and microbiological contamination of surface waters. Encroachment of urban development into rural areas has presented additional esthetic problems.

1. More specific information is needed concerning the degree of chemical and microbiological contamination of surface and ground water sources by various animal waste management practices. Adequate evaluation of a practice must take into consideration climatic conditions, soils, topography, vegetative cover, and other related factors.

2. Research is needed to develop design criteria for more efficient management, handling, and disposal of animal wastes and processing plant effluents which will minimize or eliminate pollution hazard. Improved storage and processing methods should be developed and attention given to reuse of water where feasible.

3. Economic uses of animal and other agricultural wastes should be explored and processes developed for such utilization. This would tend to minimize the potential pollution hazard.

4. Certain wastes are frequently disposed of by sprinkling or spreading on the land. This is true not only of animal wastes but also of urban sewage and processing plant effluents. Since soils and plants are involved, research is needed to develop safe criteria for such disposal which will not cause pollution of surface and ground waters. This is expecially true in arid regions where effluents may be used for ground water recharge. Soil and vegetation characteristics should be investigated in regard to their potential as filtering or purifying media. To adequately evaluate this problem, physical and chemical properties of these wastes should be adequately assessed.

Pesticides

Use of chemicals to control weeds and insects has increased at a rapid rate in the last few years. Hazards resulting from indiscriminate use of pesticides are recognized and control measures are constantly being initiated and revised to minimize these hazards. The potential role of pesticides in water pollution has been emphasized, but little reliable research data is available to document the actual severity of the problem. The problem is complicated by the large number of these chemicals currently being used.

1. Research is needed to provide relaible information on the fate of applied pesticides. This includes such factors as: a) their biodegradability in or on plant residues, in soil, and in water, b) chemical

reactions occurring between pesticides in soil and water of varying composition, c) the degree to which they leach downward in soils, d) the degree to which they are adsorbed on soil colloids and find their way into streams as sediment, and e) the effect of adsorbed pesticides on the pesticide concentration in solution and the resultant affect on aquatic life.

2. Information is needed on reliable methods for ameliorating soils and waters that may be contaminated with pesticides. In addition, the development of new methods for the application of pesticides to crops, structures, and animals to minimize the pollution hazard are necessary.

3. New pesticides should be developed which are more readily biodegradable and less toxic to humans, fish, and other wildlife. One example of this is the urgent need for better herbicides to control water weeds which will not adversely affect the quality of water for other uses.

4. Greater emphasis should be placed on the development of economical and practical non-chemical methods for insect control. This includes biological controls, such as sex attractants and sterilants, insect diseases, predators, and cultural practices.

INDUSTRIAL WATER SUPPLIES

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INTRODUCTION

This section of the research needs report expresses the viewpoint of the National Technical Advisory Committee on Water Quality Requirements for Industrial Uses. The overall program objective of water pollution abatement is to prevent further degradation of surface waters and to reduce existing pollution most economically by optimum management of our water resources. The lower the cost per unit of pollution reduction--be it obtained through fewer large or numerous small, complex or simplified treatment systems--the more quickly will pollution be reduced. Hence, it is recommended there should be two separate research and development approaches.

1. The maximum utilization of existing facilities, manpower, and knowledge. Knowledge here implies promotion of exchange of ideas and information between different plants of the same type, and plants of different types with reference to conservation, treatment, and reuse of water, as well as dissemination of the results of both industrial and federally sponsored research and development.

2. The construction of needed facilities, the training of more and better qualified manpower and the development of new knowledge. These are essential for long-term solution of the problem but are least productive of immediate results. To date this approach has received the greater attention.

An intensive effort should be made to assure that the capabilities of the existing plants are being fully utilized. In some cases, it may be possible to extend the design capability of a plant without major capital expenditure. For example, increasing the quantities of presently used chemicals or the application of new techniques or chemicals could result in an effluent of improved quality.

There is a definite need for filling the gap between research and practice. The extent to which the results of research are being applied to the elimination of pollution is not clearly documented. The engineering development and technical service programs of the FWPCA are proper steps in this direction and, indeed, need further emphasis and support.

Although it is realized that there are many gaps in our technical knowledge that warrant research, much progress in upgrading surface water quality can be made by better utilization of existing knowledge. This applies both to research findings that have not yet been adopted to plant design and operation as well as to design and operating practices used in one area but possibly unfamiliar to water technologists in other areas. Top priority should be given, therefore, to more widespread dissemination of available concepts and practices.

A basic factor common to all needed research is cost. An assessment of the potential benefit vs cost for each research project should be a prerequisite in planning the overall research program. To promote most efficient use of the research dollar, it is suggested that advisory panels comprised of technical specialists from industry and investigators in other areas be employed to review, at regular intervals, the research program for pollution control.

With the aforementioned thoughts on research developments, and technical needs, the research needs recommendations are set forth in these four major areas: 1) Pollutant effects; 2) Flow measurement, sampling, and analysis; 3) Control, treatment, and dispersal; and 4) social, political, and economic consideration.

POLLUTANT EFFECTS

The identification of pollutant effects is a prerequisite to the establishment of water quality criteria which in turn have a considerable impact upon standards. Some criteria may include such a large safety factor that compliance is unnecessarily costly. Others may have too small a factor of safety when synergistic effects are considered.

Stream standards for waters for identical uses may be based upon criteria that are valid only for a specific geographical area, while some criteria are valid for all areas. Where the criteria are inadequate, research must be conducted to establish data from which the requisite water quality criteria can be formulated.

Effect of Effluents on Coliform and Fecal Coliform Bacteria and Pathogens

The counts of the coliform and the fecal coliform bacteria form the basis for evaluating the acceptability of surface waters utilized for shellfish harvesting, recreation, and the production of a potable water supply. The use of the coliform test is very convenient and current treatment practices assure that the finished water from a well-operated water supply is free of human pathogens.

Many of the state public health officials responsible for controlling the quality of potable water are also responsible for the control of water quality for recreation. These agency people have frequently developed criteria for acceptability dependent upon the fecal coliform organism. Lacking a more acceptable basis, just such a parameter was agreed upon by the National Technical Advisory Committee on Water Quality Criteria for Recreation and Aesthetics.

Observations have indicated, 1) Streams below an active beaver dam have a very high fecal coliform count while above the dam the river has a low count: 2) The fecal coliform count rises when an industrial wastewater with organic matter and an elevated temperature enters the river below a beaver dam, and 3) When an ebb tide drains a grass-covered island on which marine birds nest, it may result that the adjacent estuary will have a high count of fecal coliform bacteria. For example, there is one case involving an island that is 30 miles from human habitation and other sources of human pollution. Therefore, fecal coliform contamination is not a definitive indication of the presence of human pathogens.

The river below a beaver dam is not considered acceptable for contact sports because of the present fecal coliform criteria. A river with a rising coliform count is considered increasingly hazardous. The high fecal coliform count in an estuary is currently grounds for closing the area for shellfish harvesting.

Research is needed to determine whether or not the following are valid conclusions.

1. Fecal coliform counts provide the best means of evaluating acceptability of recreational areas;

2. Increasing fecal coliform counts in an area where there is no external source of feces actually indicate an increasing hazard. (Do human enteric pathogens increase under conditions where fecal coliforms can increase?)

3. Human pathogens decrease in biological wastewater treatment at the same rate as the fecal coliform organisms.

Effects of Colored Waters on Sports Fishing

A better definition is needed on the effects of color upon the population dynamics and behavioral pattern of game fish species in the United States. It is important that the practical significance of color be well established.

Needs are:

1. A critical review of the literature;

2. Field surveys of typical color-polluted streams;

3. Consultation with fish wardens;

4. A review of available creel counts or other productivity data.

A comparison of fish counts in colored and uncolored waters of similar habitat and the establishment of the quantitative influence of color on game fish productivity should also be made. This will enable the costs of controlling color to different levels to be correlated with fish productivity.

Significance of Thermal Discharges

Power and industrial plants utilize water from streams, estuaries, and lakes for cooling purposes. In many instances, cooling water is returned directly to these bodies of water without treatment. Where it is treated incidental to passage through cooling towers, the effects resulting from evaporation and chemical addition on the receiving body of water may be more serious than the thermal effects.

One of the areas requiring research is the development of heat dissipating design criteria for rivers, lakes, and estuaries. In addition, the effect of thermal discharges on the chemistry of the receiving bodies of water and aquatic life require research.

Effects of Biological Refractory Organics

Information is needed on the effects of biological refractory organics (BRO) upon aquatic fauna. Reliable and sensitive experimental techniques need to be developed to measure the amounts of refractory organics absorbed by aquatic life for different concentrations and time periods. These techniques should measure or determine: 1) short-term acute toxicity; 2) long-term chronic effects; 3) mode of entry into the aquatic life; 4) areas of storage within the test species; and 5) what if any, metabolic breakdown might occur during storage.

The approach of the study should consist of steps to:

1. Review the literature to determine if any acceptable methods are available. If none is found, develop an acceptable method and,

2. Perform studies to ascertain whether or not the technique has the ability to find the five items indicated in the previous paragraph.

Stormwater Overflows

Stormwater overflows from municipal and industrial combined sewerage systems create special problems in control of water quality. Such overflows are intermittent and highly variable in quality and quantity. This has made it difficult to assess quantitatively the significance of stormwater pollutional effects. Since, during dry weather, municipal and industrial effluents receive higher degrees of treatment than during periods when stormwater conditions prevail, research investigations should be undertaken to:

1. Establish the quality and quantity of stormwater overflows from several typical municipalities and industries for different by-pass flow rates, times of flow, times between rains and seasons of the year.

2. Determine the pollutional effects of stormwater overflow on the receiving stream at the time of the storm and following stormwater flow subsidence. Such studies should include evaluation of suspended solids (floating, settleable, total), total and fecal coliform bacteria, BOD, COD, oil, and other characteristics depending on the local situation.

3. Establish a technically sound methodology for defining a specific stormwater overflow problem. Such methodology should make it possible to predict runoff from rainfall (rate and total), quality variations with time and intensity of rainfall, and total stormwater pollutional loadings for storms of different magnitude.

Accidental and Uncontrolled Spills

Transportation accidents and industrial process spills of liquids make up a significant portion of the total pollutional load on streams. These losses are usually accidental and uncontrolled. Leading examples are the spillage from a barge, rupture of a pipeline, and the overflowing of a process tank. Planning is required for adequate control and cleanup of such spills. Case histories of the accidents and the steps taken to prevent their recurrence should be prepared for training of personnel.

Guidelines should be prepared to indicate the proper control and prevention techniques being utilized. The effect of spills on the wastewater treatment plant or receiving water should also be evaluated.

The establishment of a reporting system to record major spills and note the preventive action taken would enable a rapid interchange of information. Similar industries could thereby benefit from the experience of others in abating pollution caused by accidental and uncontrolled spills.

Early Warning Systems

Systems for both in-plant and in-stream monitoring should be studied with special emphasis on the characteristics of the sending elements and the problems of operation and maintenance. Efforts should be directed towards the development of a dependable alarm system that will effectively alert the industrial operator, or notify a down-stream water user of an abnormal condition.

The available instrumentation should be surveyed and suitable systems in use should be described showing application for use in processing and receiving waters. Mathematical system models should be used to predict probable effects on the wastewater treatment plant or downstream water user.

Effects of Storage on Water Quality

The effects of storage upon water quality depend on: 1) the extent and duration of stratification; 2) the geochemistry of the soil in contact with the hypolimnion; 3) the amount and nature of the inorganic and organic matter added by the influent tributaries or outfalls at the lake surface; 4) the quantity of algae developing; and 5) the extent of vegetation developing on exposed mud flats at low water levels.

Changes in dissolved oxygen, iron, manganese, or hydrogen sulfide cause little trouble so long as the lower layer remains part of the neutral lake. When the lake is artificially formed by a hydroelectric dam, the anaerobic layer in such a lake is frequently discharged downstream through the turbines. The lack of oxygen and the presence of iron, manganese, or sulfide may cause trouble in downstream water supplies. Dissolved oxygen deficiencies of the lake may limit the ability of the lake effluents to accept organic bearing wastewater discharges (either treated or not). The presence of hydrogen sulfide near the dam creates obnoxious odors and may be destructive to many exposed metal structures near the dam. The low temperature of the lower layer and its effect downstream may produce either good or bad effects.

Basic studies on the mechanism of sulfide ion production are needed as means of reducing hydrogen sulfide odor. Research on the mechanisms of iron and manganese solution may provide the means for reducing these in the hypolimnion.

Effects of Agricultural Pollution (Nutrients, Pesticides, Salinity)

The effects of agricultural activities on water quality are as diverse as the different practices in the various parts of the country. Fish may thrive from an enriched growth of algae and fertilizer additions to crop areas or be killed by the insecticide used to protect a crop. High quality water used for irrigation produces a lush green area while a saline water may create a desert. The use of good water to restore a soil high in salts creates a groundwater which may return to the river with such a high salt content that the river cannot be used again for irrigation. Land drainage from areas with feed lots or areas with many large pasture animals may result in heavily polluted rivers. The rivers develop high BOD values as well as high fecal coliform counts.

The effect of salt concentration during irrigation upon soil fertility is a subject of intense research by agriculture. The increase in salt concentration from restoring salt-poisoned soil is a problem waiting for a practical solution. Siltation from farm lands occurs during storms in spite of water and soil conservation practices by the farmer.

It is recommended that definition of problems and areas of needed research be prepared. The sanitary engineering and the agricultural professions should be encouraged to undertake a joint study.

Ground Water Pollution

The availability of ground water decreases as population and industry increase. Therefore, the effects of polluting ground water aquifers with industrial wastes, including thermal discharges, must be understood. Ground water pollution is a long-term problem and the corrective measures available do not easily resolve or minimize the pollutional effects.

Research is required to understand the assimilation of wastes in various types of aquifers to predict the extent of pollution of the aquifers. Development should be directed towards reduction and containment procedures for these wastes.

Interaction of Waste Effluents

The mixing of two effluents may produce antagonistic or synergistic effects. For example, an acid and alkaline effluent mixture would produce a more neutral effluent than either of the components. Other waste mixtures may interact to produce a new, more harmful pollutant. The mixing of industrial with sanitary waste waters may furnish the necessary microorganisms and nutrients to aid in the biodegradation of an industrial wastewater.

The effects of mixing two particular effluents must be studied to establish whether the combination of the effluents is deleterious or advantageous. It is believed that the compilation of case histories will be advantageous to the profession.

FLOW MEASUREMENT, SAMPLING, AND ANALYSES

The foundations upon which control of water quality rest are flow measurement, sampling, and analytical procedures The information on flow measurement devices available is such that research in this particular area would have low priority. However, there is need to compile for ready reference, information on the installation and utilization of flow measuring devices. This might best be done by the Federal Water Pollution Control Administration.

The first step in securing reliable analytical data on water quality is the collection of representative samples. Natural streams vary in characteristics both in cross section and profile. The characteristics of waste effluents vary greatly with time. Consequently, care must be exercised in selecting sampling sites and procedures and in conducting evaluations of sampling plans. Good planning will dictate the minimum number of samples sufficient to insure representative data. Research in this area can provide guidance for good planning and the implementation of sampling techniques.

The development of automated facilities for sampling, analyzing, and recording data on a continuing basis is an essential step in water pollution surveillance. Such automated equipment must be reliable in operation, produce satisfactory data, and be reasonable in cost.

Pollution Surveillance Equipment

The development of automated equipment for detecting, identifying, communicating, and recording instances of pollution of any waste effluent or river basin system is an activity deserving high priority. As a necessary prerequisite for pollution surveillance, the intent of this research should be to hasten the delivery of instrumentation for early warning systems informing downstream users of water of the nature, concentrations, time of arrival, and duration of pollutants in the stream.

Research should be confined to the technical aspects of developing:

1. Reliable sensing techniques.

2. Equipment for automated sampling and measurement, telemetering, and recording of water quality characteristics.

Instrumentation is presently available for sensing temperature, specific conductance, pH, dissolved oxygen, turbidity, total and organic carbon, oxidation-reduction potential, chloride, fluoride, and certain other characteristics. The major problem is the need for constant maintenance to provide reliable data. This problem coupled with high initial cost has precluded extensive use of presently available equipment.

Sampling Program, Economics, and Validity

Development of information, including costs, useful in establishing standard procedures for sampling and compositing various type waste streams, and natural surface flows should be encouraged. Different sampling programs might be developed for each of various type waste effluents and size of rivers. The investigations should study variables as equipment, manpower, frequency, and location of sample collection, methods of compositing and preservation of samples, and costs. Each sampling program would be evaluated to determine the most economical program providing representative samples as determined by the validity of analyses commonly used.

Improved Analytical Procedures

Improved, simplified, and more exacting methods of analyses will always be needed for routine and special problems in water quality evaluation involving both major and minor constituents. Capable investigators should be encouraged to evaluate, refine, and develop analytical methods and techniques that can provide improvements in water quality investigations. Only through: 1) greater accuracy and better reproducibility of data at less cost, 2) greater sensitivity for trace constituents, and 3) the determination of unusual materials, contaminants, and pollutants, including taste and odor-producing substances, can improvement be accelerated.

Viruses: Detection and Quantification

Virological examination of waters and wastewaters is relatively new. An improved methodology, including one for the detection and quantification of the infectious hepatitis virus, is needed.

Laboratory studies should be a prologue to the development of simpler and better quantification of viruses in water and wastewater. Efforts must be made to develop the procedures for detecting and quantifying the virus causing infectious hepatitis.

Biochemical Oxygen Demand: Determination, Evaluation, and Revision

The biochemical oxygen demand (BOD) determination has been utilized for many years for the purpose of measuring the oxygen requirement for stabilization of the biologically oxidizable fraction of organically polluted water. The standard determination measures oxygen use at a single point in time for a utilization versus time relationship. Consequently, it is subject to error due to interferences with oxidation rates and it provides results that are not directly comparable from substrate to substrate. In addition, the standard, five-day test period gives information of historical rather than current value.

In contrast, the ultimate oxygen demand can be determined accurately and reproducibly. As a theoretically defined entity, the ultimate demand is useful for comparing wastewaters, for evaluating treatment efficiencies, and for predicting oxygen utilization in treatment facilities and natural waters.

It may be possible to develop practical methodology for reliably estimating the ultimate oxygen demand of biologically oxidizable materials that can be completed in 10 minutes. Research should be encouraged to develop the methodology and instrumentation necessary to attain this objective.

CONTROL, TREATMENT, AND DISPOSAL

Rapid progress toward upgrading the quality of surface waters can be made by encouraging measures that: 1) reduce the volume of water used, thereby reducing the size and cost of the required wastewater treatment facilities, and 2) combine for treating the wastes from as many sources (industrial and municipal) as practical in each geographic area, thereby minimizing both the construction and operating costs.

Suggested research needs and priorities are:

Control

Four general approaches may be applied in order to limit the adverse effects of industrial water uses on surface water quality.

1. Minimize the volume of water entering the wastewater treatment plant.

2. Minimize the quantity of pollutants entering the wastewater treatment plant.

3. Minimize the quantity of pollutants entering surface waters without treatment.

4. Minimize the quantity of water withdrawn from surface sources.

The aforementioned control measures are ordinarily much less expensive than the alternative of supplying and operating larger and more costly treatment works.

Some typical control measures are: 1) water conservation measures (e.g., the use of closed cooling systems, counter-current rinsing, in-plant reuse of industrial waters, and use of municipal waste treatment plant effluent); and 2) industrial plant steps (e.g., process modifications, raw materials substitution, and good housekeeping in the plant, particularly the avoidance of unnecessary discharges).

Research on such control measures is not urgently needed, but there is a real need for strong, positive steps to widely disseminate information on water and wastewater control practices already in use in local geographical areas and in some industrial plants. The engineering profession must recognize the necessity for the routine inclusion of water and wastewater control measures as an integral part of process and plant design. Local management must assume the responsibility for continuing pollution control through plant operating practices.

For these purposes, the FWPCA should support efforts to compile existing information on water and wastewater control methods utilized in industrial plant design and operation. Such information should be brought repeatedly to the attention of as many engineers, managers, and operators as possible. This may be accomplished through the preparation and distribution of: 1) manuals on design and operating practices for minimizing water use and wastewater production; and 2) audio-visual aids for use in training.

Moreover, it is suggested that the Federal Water Pollution Control Administration itself present or encourage technical societies, or other appropriate organizations or groups to hold seminars and short courses on desirable design and operating practices.

Treatment

Suggested research topics concerned primarily with treatment are presented in order of decreasing priority.

Integration of industrial and sanitary wastes. The bill for pollution control, totaling billions of dollars, will ultimately be paid by the American people. Whether this bill is paid through higher prices for the products of industry, taxes, sewer rental charges, or other means, is immaterial. The objective should be to complete the task at the least possible cost.

The treatment alternative of combining industrial and municipal wastewaters may prove the most economical as the cost of construction and operation of a large wastewater treatment plant is usually less than the combined costs of numerous smaller plants. Likewise, construction of mixing and holding basins at large disposal plants would minimize the detrimental effects from slugs of acid, alkaline, or toxic effluents, and reduce the need for "on the spot" neutralization of alkaline and acid wastes (a practice which increases the total solids of the final combined wastewaters). Holding basins could also make possible the many benefits resulting from a more uniform flow rate through wastewater treatment and disposal plants.

Research should be directed particularly toward developing improved understanding of the treatability of various volume and strength ratios of representative industrial and municipal wastes. This would be in effect a continuation of the type of research carried out in recent years at the Taft Sanitary Engineering Center on the effects of various industrial waste components on the functioning of biological waste treatment processes.

Such a program should include the effectiveness of biological treatment in handling wastes containing oils of both vegetable and mineral origin, as well as other common components of industrial wastes. It should also be concerned with the effects of industrial in-plant pretreatment of wastes upon their acceptability in municipal treatment plants. This topic appears particularly suitable for cooperative bench scale and pilot plant research carried out at municipal waste treatment plants jointly by industries and municipalities.

Refractory waste treatment. This particularly difficult topic is closely related to the question of ultimate disposal of refractory residues.

Ultimate disposal methods will inevitably be required for inorganic refractories, such as dissolved electrolytes. All measures should be taken to reduce the volume of refractory wastes by use of recycling and recovery procedures or other means.

Acid mine drainage is a major and serious case of refractory inorganic wastes. Limited basic research programs on the treatment of mine drainage are in progress under the sponsorship of various governmental agencies. The majority of the work has been confined to the treatment of mine drainage by lime neutralization and at present no intense effort is being directed towards the prevention of acid production within the mines. Source control investigations on inactive or abandoned mines are an imperative first step towards the development of the overall acid mine drainage program. Funds should be supplied for studies on methods for preventing formation of acid at the source since this would also have the desirable effect of reducing the amount of inorganic solids entering surface waters.

Many refractory organics, such as highly toxic materials, may be subject to non-biological methods of destruction, such as catalytic aqueous oxidation or incineration. This is an area which appears to be particularly suited for fundamental research.

Reduction of phosphate pollution. Indications of widespread undesirable effects from phosphate residuals in water accelerating the eutrophication of lakes and promoting the growth of taste and odor causing algae in surface water supplies make it important to find effective methods for minimizing the phosphate content of wastewaters.

In addition to the problem of phosphate from agricultural activities, research is needed in three areas of special concern to industry.

1. Development of processes for removal of phosphates at levels as high as 400 ppm and in the presence of various types of substrates, particularly organic compounds that adversely affect the handling and disposal properties of precipitated sludges. Sludge conditioning methods should also be investigated.

2. Development of effective and economical nonphosphate methods for the internal treatment of boiler waters, cooling waters, and public water supplies. The phosphates now used for scale and corrosion control contribute appreciably to the phosphate problem of waste disposal plants and surface waters.

3. Development of effective and economical phosphate-free detergents. Present day detergents are major contributors to the phosphate problem.

Reduction of colloidal materials. The problem of removal of colloidal solids covers a wide spectrum encompassing color, turbidity, and oily emulsions (organic and inorganic) present in both raw surface waters and wastewater effluents. The purpose of this research would be to review the fundamentals of colloidal precipitation and to develop more effective and economical methods of colloid removal.

A survey of work now being carried out in universities and research centers on these phases, complemented by knowledge developed by manufacturers of equipment and chemicals applicable to this problem, should be initiated. In-plant treatment of oil emulsions at the source may: 1) provide maximum concentration and minimum volume; 2) allow possible recovery of product; and 3) result in a more easily handled precipitate for disposal.

The research effort should encompass industrial operations producing oily emulsions and include field demonstrations of laboratory developments. The economic separation of the precipitated colloid and the removal of released oil are prime factors for consideration.

In-river treatment. The concept of in-river treatment of wastes refers to the use of physical or chemical procedures to augment or assist the natural assimilation capacity of a surface water. These may range from skimming surface oil to measures for increasing the dissolved oxygen concentration.

This research would be particularly valuable for the reduction of "naturally occurring" pollution in rivers draining swampy, wooded, or agricultural areas. It should start with a study of the sources and characteristics of pollution and continue with evaluation of various reaeration techniques and other treatment methods that promise economic feasibility for reduction of sediment. organics, nutrients, or other undesirable constituents.

A special area for research is the removal of petroleum products or other lighter-than-water organic liquids discharged into rivers, lakes, or harbors as a result of tanker collisions or other accidental spills. In addition to the design of effective and readily transportable skimming equipment, this research should seek to develop adsorbents and coagulants that would collect the oil for easier removal and disposal.

Disposal

The safe and orderly disposal of liquid and solid residues derived from water and wastewater treatment must accompany all pollution abatement programs. These wastes include those materials which remain in solution or suspension after all reasonable treatment procedures have been applied and the major part of the original waste has been made acceptable for discharge to the receiving stream.

Sludge disposal is a major problem. This widespread and critical disposal problem involves the sludges produced in municipal and industrial water and wastewater treatment as well as industrial processes. These sludges may be either organic or inorganic in nature and possess a wide range of physical and chemical characteristics.

A survey should be made of the methods now in use, such as solids-water separation, drying, incineration, sanitary land-fill, in-plant reuse, and by-product manufacture. Hopefully, the techniques used successfully by one industry can be applied in solving the problem for others. The survey will reveal principal problem areas and provide information necessary to describe meaningful research and pilot plant studies.

Better methods for reducing the water content of sludges are needed. For organic sludges, procedures worthy of further study are pre-treatment steps such as aerobic and anaerobic digestion, wet oxidation, composting, and chemical conditioning as they relate to the final de-watering steps of centrifugation, vacuum filtration, and incineration.

Liquid refractory wastes. Treated effluents may still contain dissolved materials that prohibit discharge to surface streams. These materials include numerous substances ranging from large amounts of harmless salts to toxic constituents. Satisfactory solutions to the disposal of these materials are not available. Possible areas requiring research and investigation include: 1) studies of deep well injection practices; 2) surveys to inventory suitable strata; and 3) development of methods to produce cavities in the earth for disposal.

Disposal at sea is a possibility, but oceanographic investigations are needed to determine the long-range feasibility of this approach. The process of casting wastes into concrete for burial or dumping at sea is also a possibility.

Intermittent and seasonal discharges. This type of waste production can be the cause of serious pollution problems since on-site treatment and disposal facilities are not always provided. Examples of the intermittent and seasonal discharges are those from small canneries, wineries, slaughter houses, dairies, etc.

It is recommended that studies be initiated to evaluate the types and volumes of these wastes and to develop handling methods. Five specific research needs are suggested.

1. Methods of pre-treatment to permit storage in ponds (such as screening, sedimentation, and pressure flotation) to remove suspended solids.

2. Design features of aeration systems to prevent odor production from septic wastes and to promote aerobic digestion.

3. Methods of treatment for effluents from storage ponds to allow their periodic discharge to surface waters (for example, the use of polyelectrolytes for removal of bacterial cell debris).

4. Anaerobic methods of treatment in deep ponds which prevent or control the production of malodorous gases (for example, styrofoam covers or sheet plastic hoods over the pond surface).

5. Design of tank truck collection system for delivering small volumes of strong wastes to central treatment plant.

Small rate discharges. With the substantial reduction of pollution from major sources, the cumulative effects of a large number of individual, low rate discharges will gradually become apparent. A typical example would be a one-half gallon per minute bleed of treated water from the refrigeration cooling tower in a supermarket or the blowdown of a small but highly concentrated stream from an industrial recycle system.

Economic and technical factors appear to make it unlikely that on-site waste treatment equipment will be feasible for many of these sources. Acceptance of such wastes into municipal sewers would appear to be the best procedure.

More information is desired on the effects of the composition and strength of such wastes relative to the size of the receiving treatment plant. Studies are also needed on the effects of the pollutants on disposal plant operation and on the development of adsorbents for specific pollutants, particularly chemicals used for treatment of boiler or cooling waters.

SOCIAL, POLITICAL, AND ECONOMICAL CONSIDERATIONS

The basic social, political, and economic considerations comprise eight suggested areas of research. The emphasis here is to provide better answers to the following topics, listed in the order of decreasing priority.

1. The method that will provide optimum overall planning for the use of water in a river basin.

2. The extent to which the rather common industrial practice of using water of impaired quality can beneficially be extended.

3. The extent to which higher standards of quality for surface water will increase reuse of water within industry.

4. The actual cost to improve various quality characteristics of water.

5. The existing cost-benefit ratio of present programs for river management.

6. The proposed measures for control of air pollution and their effects upon the pollution of water.

7. Municipal charges for handling industrial wastewater.

8. Municipal charges for potable water.

Development of Optimum Techniques for Water Management

A method is needed for planning the use of water in a river basin or functional portion of a basin which will produce and maintain the most beneficial socio-economic effect for the system. Such a method should ultimately be capable of including all of the significant variables likely to be encountered in any river basin.

One approach involves the following steps. 1) Develop a model for optimization analysis which could handle the many physical variables influencing the physical-economic relationships in a stream system.

2) derive a practical cost function for various combinations of steps in the treatment of water and wastewater, and 3) transform the stream system into a form applicable to the theory of maximum principle involved in process analysis.

Utilization of Water of Impaired Quality for Industrial Processing

Water which does not meet existing water quality standards may be considered water of impaired quality. The economic feasibility of using water of impaired quality to a greater extent in industrial processing needs further study. An initial determination on a national level of the extent of such process water use by industry is desirable.

The acceptability of any water for a process use is dependent on certain quality and economic considerations. The use of water of impaired quality will depend upon an economic evaluation of relative costs: 1) alternative available sources of water, 2) process and product quality, 3) effect on equipment, and 4) cost of wastewater treatment and disposal of the water after use. The overall problem consists of determining the cost incurred by using a water of lower quality. The preparation of examples showing the methodology required to develop relative costs for the utilization of water of varying qualities would be of help to industry.

Impact of Wastewater Effluent Requirements on Water Use

Water quality requirements established by state and federal agencies will affect the volume of industrial intake water. The reasons for differences in water intake per unit of product should be investigated. As the quality of the effluent waters from municipal sewage treatment or industrial plants is improved, these effluents will become a source of water for use by industrial plants or by agriculture.

Information on cases of reuse resulting from improvement in the quality of a wastewater may be collected from the technical literature. In addition, managers of both municipal and industrial water and wastewater treatment operations should supply information they have available on reuse potential.

Economics of Altering Water Quality

Since a general comprehension of the costs of altering the quality of water is desirable, the collection, critical review, and correlation of information on costs of specific processes for altering the quality of water is recommended. These costs may be influenced by water processing, initial water composition and characteristics, and extent of alteration.

Sources of information for this area of research would be the management of municipal water treatment and sewage treatment plants, the management of industrial operations preparing waters of widely different quality for specific process uses and treating wastewaters for reuse or discharge.

The information to be collected should encompass the economic factors of altering water quality. The economic factors of altering water quality include: 1) the capital investment, 2) the year in which it was made, and 3) the operating cost (comprising maintenance, labor, power, chemicals, depreciation, and cost of capital.)

Economics of River Basin Water Management

The social, political, economic, and technical aspects of existing river basin management programs should be studied in light of their history and current cost-benefit ratio. The history of their formation, planning, and execution should be reviewed to determine whether the results thus far produced are worth the total expenditures, and whether the same or better results could be produced in less time or at lower cost in other river basins. Information on the total cost-benefit ratio achieved may have considerable value for the future. It would also be desirable to determine whether any specific objective of a program has been so costly to attain that the objective should be modified or abandoned in future basin management programs.

Air Pollution-Water Pollution Interchange

The promulgation of air quality standards will result in the increased use of equipment to wet scrub gaseous and particulate matter from air streams with water or various neutralizing solutions. Discharge of these waste waters to sewers or waterways may create new water pollution problems or intensify old ones.

It would be desirable to study the composition of aqueous discharges from air pollution control equipment. The effects of these discharges upon treatment plants for sewage and industrial wastes, as well as upon receiving bodies of water, should be explored.

Logic of Sewer Rental Charges for Industrial Wastes

A logical basis is needed for sewer rental charges levied on major industries. For example, major industries may be considered as those industry groups defined by a four digit Standard Industrial Classification Code (SIC code) which discharge 10 billion gallons or more per year to public sewers. A study to develop such a logical basis might require determination of all cost factors involved in providing municipal wastewater disposal service. From these costs it may be feasible to develop a surcharge formula related to volume and composition of wastewater. It may be found that in many instances the quantity factor comprises such a major portion of the total costs that monitoring the composition of wastewater at specific points of origin costs more than it is worth.

Logic of Charges for Water

Existing charges to water users for providing various quantities of water under different conditions of availability and use may become progressively less appropriate with time. Relationship between costs and charges might lead to more appropriate pricing schedules.

Actual annual cost data for obtaining, treating, and distributing water could be obtained from municipal water works representing extreme and intermediate conditions of availability, demand, and degree of treatment. The effect of pricing schedules as a means of conserving limited supplies might also be considered.

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